Mercury Use in the Goldmining Industry

A retrospective examination of elemental mercury use in the gold mining industry of the West Coast of New Zealand in the period 1984 – 1988.

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By

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Massey University Human Ethics Committee:

This project has been evaluated by peer review and judged to be low risk. Consequently it has not been reviewed by one of the University's Human Ethics Committees. The researcher named above is responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher, please contact Professor Sylivia Rumball, Assistant to the Vice-chancellor (Ethics & Equity), telephone 06.3505249, e-mail humanethics@massey.ac.nz.

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The terms, acronyms and abbreviations below appear in this document.

< - Less than;

> - Greater than;

℃ - Degree Celsius [centigrade];

µg – microgram [10^{-6} gram];

µg/kg body weight per day – Micrograms per kilogram body weight per day; units used for describing intakes (or doses) of mercury such as intakes that are considered safe for humans.

µmol - micromole is 1 millionth of a mole;

ADI - Acceptable daily intake;

AMAP - The Arctic Monitoring and Assessment Programme;

ATSDR – USA Agency for Toxic Substances and Disease Registry;

Balance - Totality of quantitative estimates of input and output substance fluxes for a given geophysical reservoir or societal entity;

bw - Body weight;

Dry deposition – The transport of trace gases and particles to the earth's surface which is an important loss process for many reactive and soluble trace gases. It is of a continuous character independent of the occurrence or absence of atmospheric precipitation;

EC – European Community. Now called European Union with 27 member states.

EMEP – Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (under the LRTAP Convention);

ESP – Electrostatic precipitator; equipment used to reduce emissions of certain pollutants from combustion flue gases;

FAO – Food and Agriculture Organization;

FF - Fabric filter; filter type used to capture particulate matter (here: from combustion flue gases);

FGD – Flue gas desulphurization; process of/equipment for primarily minimizing emissions of sulphur from combustion flue gases;

GEF - Global Environment Facility;

Hg – Mercury;

Hg^0 - Elemental mercury;

Hg^{2+} - Divalent mercury - the dominating mercury form in organic and inorganic mercury compounds. In the atmosphere, mercury species with divalent mercury are more easily washed out of the air with precipitation and deposited than elemental mercury;

Hg_p - Particulate mercury - mercury bound in, or adsorbed on, particulate material. In the atmosphere, particulate mercury is deposited much faster than elemental mercury;

IARC - International Agency for Research on Cancer;

ILO - International Labor Organization;

IPCS – International Programme on Chemical Safety;

kg – kilogram;

l or L – Litre;

LC_{50} - Lethal concentration, 50%; concentration of toxic substance in a medium (for example water) at which 50% of the individuals in the toxicity test sample die; a unit used to describe the level of toxicity of a substance to a specific species, for example fish;

LD_{50} - Lethal dose, 50%; dose (intake) of a toxic substance at which 50% of the individuals in the toxicity test sample die; a unit used to describe the level of toxicity of a substance to a specific species, for example in laboratory tests on mice, birds or other animals;

Life-time - In atmospheric physio-chemistry: Time during which the first order processes (or totality of the first order processes) of scavenging results in mercury species mass reduction in **e** times in a geophysical reservoir; for a reservoir with homogeneous mercury species distribution the life-time is equal to the ratio of the mass contained in the reservoir to scavenging rate. Since the mass of mercury in the reservoir left to be reacted or removed decreases over time, the amount reacted or removed per unit of time decreases in a natural logarithmic fashion. For example, a lifetime of mercury of one year, does not mean that it would all be gone in one year if emissions were zero. It means that the rate of removal at the start of the time period in terms of mass per unit time would remove it all in one year, but since the rate of removal decreases as the mass of mercury left decreased, the amount of mercury left after one year would be (1/e) times the initial mass, where "e" is 2.71828183 defined to 8 decimals. In descriptions of life-cycles of products: The time span from when the product is put into use (usually time of purchase) until it is no longer used or discarded;

LNB – Low-NO_x burner; utility boiler combustion technology designed specifically to generate relatively low levels of nitrogen oxides;

Load - The intensity of input of pollutants to a given ecosystem from the environment; atmospheric load - the intensity of input from the atmosphere;

LOEL - Lowest observed effect level (also called **LOAEL** – lowest observed adverse effect level); for toxic or other effects imposed on organisms or experienced by humans;

LRTAP Convention – Convention on Long-Range Transboundary Air Pollution;

MBL – Marine boundary layer; the air right over the ocean surface, where exchange of mercury between the two compartments takes place;

MethylHg or MeHg – Methyl mercury;

Metric ton or tonne – 1000 kg;

mg – milligram (10^{-3} gram);

Mol or mole - is the atomic weight of a molecule of the chemical in grams. E.g. 1 mole of mercury is 200.59g.

MRL – Minimum risk level; term used in evaluation of risk of toxic effects from various chemicals (such as methylmercury) on humans; the MRL is defined by US ATSDR as an estimate of the level of human exposure to a chemical that does not entail appreciable risk of adverse non-cancer health effects (see section 4.2);

MSW – Municipal solid waste;

MW – Megawatt a unit of electrical power;

MWC – Municipal waste combustor;

MWh – Megawatt-hour is a unit of energy most commonly used to express amounts of energy.

Natural emission - Input to the atmosphere, which is not connected with current or previous human activity;

NEMA – National Electrical Manufacturers Association (in the USA)

ng – nanogram (10^{-9} gram);

NGO - Non-governmental organization;

NOEL - No observed effect level (also called NOAEL – no observed adverse effect level); for toxic or other effects imposed on organisms or experienced by humans;

NRC – National Research Council of the United States of America is under the auspices of the National Academy of Sciences (NAS), the National Academy of Engineering (NAE), and the Institute of Medicine (IOM). The NAS, NAE, IOM, and NRC are part of a private, no-profit institution that provides science, technology and health policy advice under a congressional charter signed by President Abraham Lincoln that was originally granted to the NAS in 1863. Under this charter, the NRC was established in 1916, the NAE in 1964, and the IOM in 1970. The four organizations are collectively referred to as the National Academies

OECD - Organization for Economic Cooperation and Development;

pg – picogram (10^{-12} gram);

POPs - Persistent Organic Pollutants;

ppb – parts per billion;

ppm - parts per million;

Pre-industrial state - A conventional term implying the state of the natural [mercury] cycle before the beginning of human industrial activity; in Europe the beginning of a noticeable production and consumption of mercury is related to medieval centuries;

PS - Particle scrubber; equipment designed to reduce emissions of particles from combustion flue gases

Re-emission - Secondary input to the atmosphere from geochemical reservoirs (soil, sea water, fresh water bodies) where mercury has been accumulating as a result of previous and current human activity;

RfD – Reference dose; term used in evaluation of risk of toxic effects various chemicals [such as methylmercury] on humans; the RfD is defined by US EPA as an estimate [with uncertainty spanning perhaps an order of magnitude] of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime;

SCR - Selective catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

SDA - Spray dryer adsorber system; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

Slag – A substance produced by mixing chemicals with metal that has been heated until it is liquid in order to remove unwanted substances from it.

SNCR - Selective non-catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

TLV - Threshold limit values are guidelines [not standards] prepared by the American Conference of Governmental industrial Hygienists, Inc [ACGIH] to assist industrial hygienists in making decisions regarding safe levels of exposure to various hazards found in the workplace. They reflect the level of exposure that the typical worker can experience without an unreasonable risk of disease or injury. TLVs are not quantitative estimates of risk at different exposure levels or by different routes of exposure;

Torr - Is a non-SI unit of pressure defined as 1/760 of an atmosphere;

TWA - Time weighted average. The average exposure to a contaminant that a worker may be exposed to without adverse effect over a period such of an 8 hour day or 40 hour week. E.g. mercury vapour TWA is 0.05 µmol/m^3;

UN - United Nations;

UNCED - United Nations Conference on Environment and Development;

UNEP - United Nations Environment Programme;

US EPA – Environmental Protection Agency of the United States of America;

USA – United States of America;

Wet deposition - Flux of substance from the atmosphere onto the underlying surface with atmospheric precipitation;

WHO - World Health Organization.

Properties of mercury.

Atomic number: 80

Density: 13.5336 grams per cubic centimetre

Melting point: -38.83^0C [234.32K] -37.89^0F

Description: Silvery, odourless, heavy liquid

Molecular formula: Hg

Molecular weight: 200.59 g / mol

Period number: 6

Group number 12

Boiling point: 356.7 ℃ [629.88^0 K] 674.11℉

Phase at room temperature: Liquid

Element classification: Metal

Vapour pressure: 0.002 torr @ 25℃

Vanderwaals radius: 0.157nm

Solubility: Soluble in concentrated nitric and hot sulphuric acid; dissolves to some extent in lipids

CAS number: 7439-97-6

Oxidation states: +2, +1

Inhalation reference exposure level: 0.09 mg / m^3

TWA : 0.05 mg / m^3

Fig 1. Map of New Zealand.

Executive Summary.

The use of toxic metallic mercury for gold recovery through amalgamation and retorting is a well known process and has been in use around the World for centuries (Malm 1998). In New Zealand it has been in use since the early gold rushes of the 1870s. Its toxicity to humans and the environment has been well researched world-wide with mercury vapour reported to have killed 15 miners and made many more ill in a Turkish mercury mine (Trakhenberg 1974). The notification of a gold worker with mercury poisoning in the West Coast town of Greymouth, New Zealand in late 1985, the first such notification in New Zealand, raised the author's interest in the local gold mining industry and the use of mercury to save gold. The manner in which mercury was used in New Zealand in the early years of gold recovery has not been researched and although no records have been kept it was known to be used extensively.

In this historical 1980s study that is being re-examined, the effects of mercury usage on workers has been observed via on- site visits, observation of work processes, worker discussion, urinalysis, air measurement, personal dose measurement and the use of a subjective questionnaire to record participant's symptoms. Participants [n =16] were selected from different companies to take part in the study and a control group [n =12] was used. Altogether a total of 25 mining sites were involved in the study.

The research identified sources of mercury contamination and problem areas in the gold mining industry that were a cause for concern that needed to be addressed. However, a collapse of the gold price in late 1988 led to the cessation of gold mining in New Zealand almost overnight and the results of the study were never published. Small scale gold mining is once again being considered as a viable industry within New Zealand due to the high price of gold and as mercury is still considered easy to use, and cheap, it will remain the main means of recovering gold. This view is reinforced by current research papers (EPA 1997; Agency 1999; Hentschel et al. 2002). Gold is still plentiful in the West Coast region but, because it is in the ground, it is expensive to get out.

The study covered the years 1984–1988 and found health risks for users of metallic mercury with a poor understanding among all users of the hazards of mercury. Mercury use in the gold mining industry in New Zealand was not well managed and created a risk to the health of workers through high mercury in air levels [Hg–air] in the work environment, from spillage of mercury and poor work practices. The study proved the existence of a microenvironment that contaminated worker's breathing zones. This microenvironment was not acknowledged within the industry and if we are to ensure that worker's total exposure dose is measured, it is very important that it be acknowledged and acted on. The mercury urine levels [Hg–U] and mercury air levels [Hg–air]

were found to have a good relationship. This correlation between mercury vapour exposure and urinalysis results has been proved by others (Piotrowski 1975; Yoshida 1985; Roels et al. 1987; Naleway et al. 1991).

The use of a subjective questionnaire, in conjunction with the urinalysis, to capture the feelings of workers was a useful tool for evaluating the overall health effects of mercury contamination. This reinforced work done in earlier studies (Smith et al. 1970; Roels at al. 1985; Rosenman et al. 1986). Conclusions and recommendations are made to ensure future use of metallic mercury in the gold mining industry does not present a risk to users.

Mercury was known to be used on the West coast in vast quantities [unfortunately, no records of quantity exist] and due to spillage and carelessness in handling, much of it was lost to the waterways and general environment. Once in the silts it undergoes changes that make it available to the food chain and it has been found in local fish stocks. High mercury levels in fish, amphibians and invertebrates downstream of mining sites are a consequence of historic mercury use (USGS 2007). This environmental contamination can, and does, have a detrimental effect on the health of animals and humans (WHO 1976; WHO 1991; UNEP 2002; UNEP 2005). Recent studies give a better understanding of mercury distribution, transport and transformation processes in old gold mining sites (UNEP 2005).

This study has not been previously published and the findings have not been made widely known although the industry was kept abreast of the study at the time. This thesis has brought together the data from the earlier study and evaluated it with some recent / modern research.

Chapter 1. Introduction.

New Zealand was colonised primarily for agricultural land rather than for its mineral wealth. As an increasing number of European settlers arrived after 1840, they started to search for metals [particularly gold] and coal. Gold rushes in the 1860s led to the migration of men to hitherto remote areas in Otago, the West Coast, and Coromandel. New Zealand is self-sufficient in many mineral resources, and exports substantial amounts of gold, silver, iron sands and high-grade coal. The mining industry contributes to several major sectors of the economy, including agriculture, energy, construction, transport and manufacturing (Statistics New Zealand 2006).

The West Coast of New Zealand's South Island was opened up in the 1860s by the discovery of gold. Although the easy gold was worked out, there has always remained those hardy souls who have carried on trying to find another El Dorado. It is acknowledged that there is more gold left on the West Coast than was ever taken out, however, much of it requires removing tonnes of overburden to get (MED 2007) and, as this requires the use of heavy machinery, is not economic unless the World gold price is high.

The last gold rush on the West Coast took place in the late 1890s with the last remaining quartz gold mine at Waiuta ceasing work in 1951 (May 1962). After that time the price of gold remained low and it was not until late 1970 early 1980 that the gold price began to increase to a level that made it economical to work the deeper claims. In the period 1982-1988 a mini gold rush occurred on the West Coast and over 200 licences were issued to mine or prospect for gold (MED 2007), however, not all these were worked at the same time as some were purely speculative.

The main means of recovering gold during this period involved the use of elemental mercury and amalgamation. The mining industry had little knowledge of the hazards of mercury but knew that it was an easy and cheap way of recovering gold. The extent of employee's knowledge covered methods of use with limited safety instruction and no information on the metal's toxicity.

In 1985 a case of severe mercury poisoning in a person working in the gold mining industry was notified to the Mines Inspectorate responsible for mine safety. This period was before the establishment of Occupational Safety and Health [OSH] in New Zealand and, at that time, the local Health Authority provided advice to the Mining Inspectorate on health and occupational

related issues. This poisoning notification was the catalyst for the author's decision to carry out a study of mercury use in the local mining industry. The study was carried out over the period [1984–1988]. In 1988 the world price of gold dropped below an economic level and mining ceased almost overnight. It is this 1984-1988 study that is being re-examined and re-evaluated in this thesis.

The World gold price [2007] has risen to a level [NZ$1000] that makes it profitable for mining with new mines being opened up and old claims being reworked. Although there are new methods available to save gold that do not involve mercury, they are expensive and more time consuming, and more likely to be used by large companies that can afford the financial outlay. It is probable that small scale mining, the majority in this region, will again use mercury as the main means for their gold recovery. This renewed interest in gold mining justifies re-examining the 1984-1988 study so that risks/ problems identified can be addressed if the New Zealand industry is restarted.

1.1 Outline of thesis.

The thesis begins with an introduction and brief history to give the reader a little back ground. The area of the West Coast covered by this thesis is shown on the map on page 11. In the original study a small number [n=25] of West Coast mine sites were visited governed by time, workplace and travel constraints. Participants were a representative sample of the industry as a whole.

1.2. Literature search.

A literature search on mercury covered the history, uses, properties, and problems associated with its use by man. Research papers were reviewed and the World Wide Web [www] was utilised.

1.3. Methodology.

The methodology used is discussed in detail with a description of the methods involved, equipment used and their technical specifications.

1.4. Results.

The results are provided in graph and table format with discussion of the findings as they relate to each section.

1.5. Discussion.

The discussion covers the findings of the research in depth and the results are evaluated. The impact of mercury use, based on these findings, on the safety of workers employed in the gold mining industry is covered.

1.6. Conclusion.

The conclusions summarize the main points that have been identified and the importance of each one is explained.

1.7. Recommendations.

A number of recommendations are made with a view to encouraging their discussion and adoption by the industry and authorities.

1.8. Limitations.

Limitations and possible bias were identified, noted and discussed.

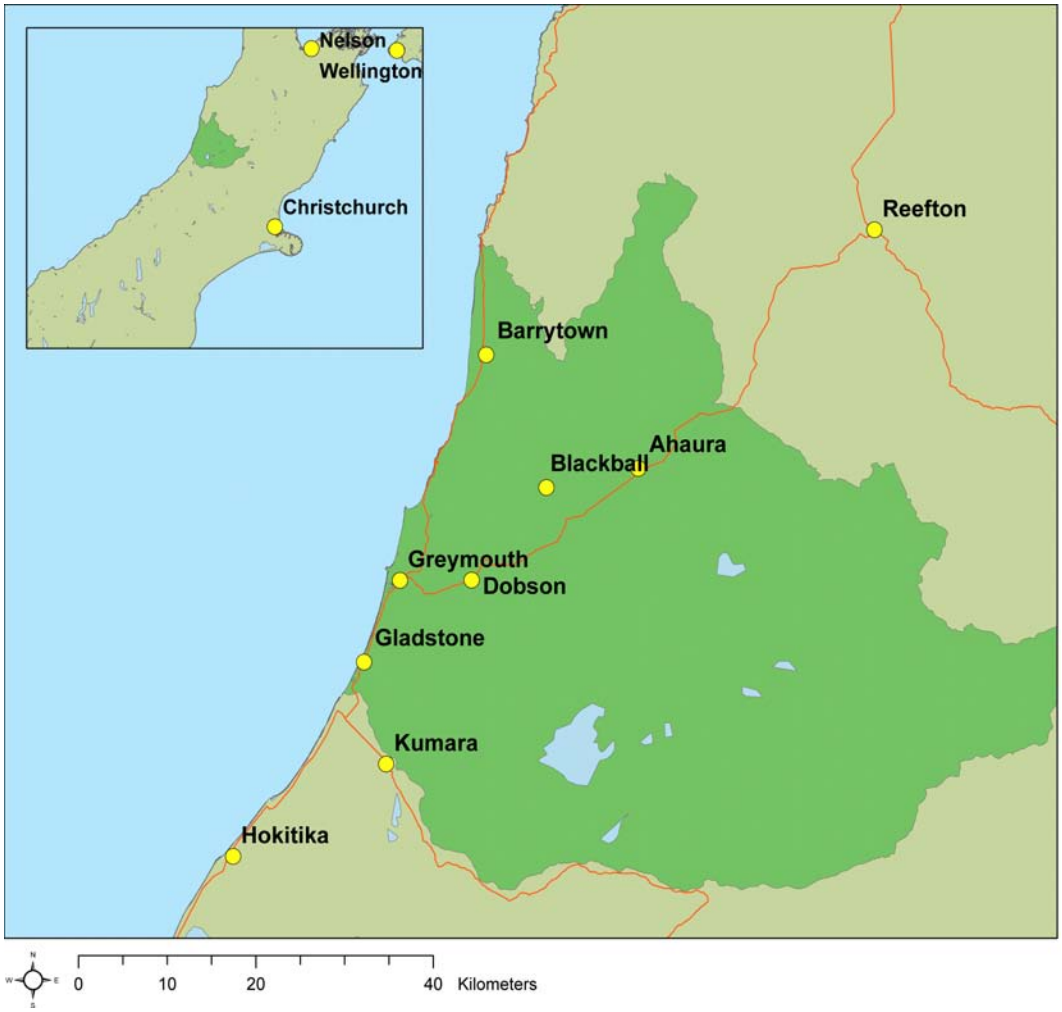
1.9. Future research.

During the study gaps in knowledge were identified and these have been noted with possible areas of further study briefly discussed.

Chapter 2 . Introduction to the West Coast.

The area of the West Coast covered by this study is shown in green in the map of Fig 2 below**.**

Fig. 2. Study area in which mine sites visited were located.



2.1. West Coast land mass.

The West Coast region [Te Kaunihera Whakakotahi O Te Tai Poutini[1]] of New Zealand's South Island is a narrow wedge of land located between the Southern Alps and the Tasman Sea. Geographically remote and bounded by mountain ranges to the east and the Tasman Sea to the west, the West Coast is a World Heritage Area - a region of snow clad peaks, lakes, glaciers, rivers and forests. It extends over a distance of 600 km from Kahurangi Point in the north to Awarua Point in the south. It has a land area of 23,000 square kilometres, [2.300,000 hectares] or 8.5% of New Zealand's land area. The West Coast is the third largest region by land mass in New Zealand but, with only 1% of New Zealand's population at 31,326 (Statistics 2006) it is the most sparsely populated province in the country. It has a density of 1.4 people per sq km compared to 13.1 people per sq km nationally. Prior to the discovery of gold, the West Coast was home to Maori, the original native inhabitants of New Zealand, who had settlements along the coast. Isolated from other regions such as Canterbury to the east and Nelson to the north by high mountains [the Southern Alps], it is a region distinguished from the rest of New Zealand by geography, climate, terrain, history and way of life.

[1] Maori are the indigenous people of New Zealand and this is their name for the West Coast

With a thin elongated shape the region does not exceed 100 km at its widest but is over 600 km long. Of the total landmass, 87% is Crown owned with only 13% private property. The Alpine Fault, an earthquake fault-line, runs north / south through the length of the region and to the East of the fault are deeply dissected, forested mountain ranges. Rivers and streams are steeply graded with plains areas in river valleys and along the coast. Most habitation is along the Coast and on the river flats (WCRC 2007).

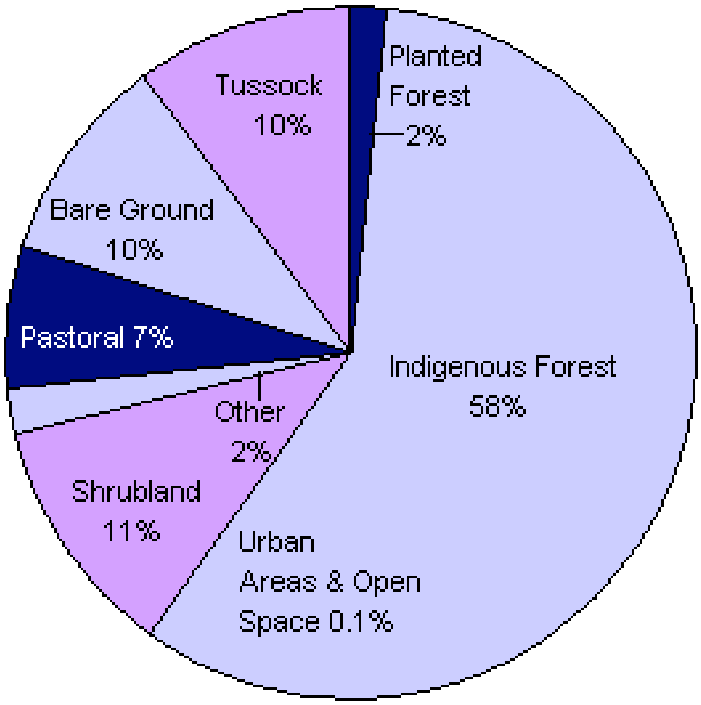
2.2. Climate.

The region receives a generous and reliable rainfall that exceeds 8000 mm annually in the southern mountains and declining to 2000 mm at the coast, and in the north. At high altitudes there are snowfalls in the winter months. In the region's southern parts this contributes to glaciers that reach to within a few hundred metres above sea level. Away from these areas to the north, the climate is generally mild and near the coast sunshine hours are similar to those experienced on the east coast. The more sheltered locations provide a variety of different microclimates. Sub tropical fruits can be grown in the northern part and there are proposals [and trials] to grow commercial crops.

2.3. Land coverage

The West Coast is a region different to the rest of New Zealand in that approximately 60% of the land mass is covered in native forest. There are small areas of exotic forestry, mainly pines that were established as the milling industry moved away from native timbers. Natural pasture land is rare and wetlands, once common, are being drained for farmland. West Coast native forest, the largest in New Zealand, is protected from logging. The farmed land is used mainly for dairy and dry stock production.

Fig. 3. West Coast land cover as of 1985.



Source: WCRC 2007.

2.4. Minerals.

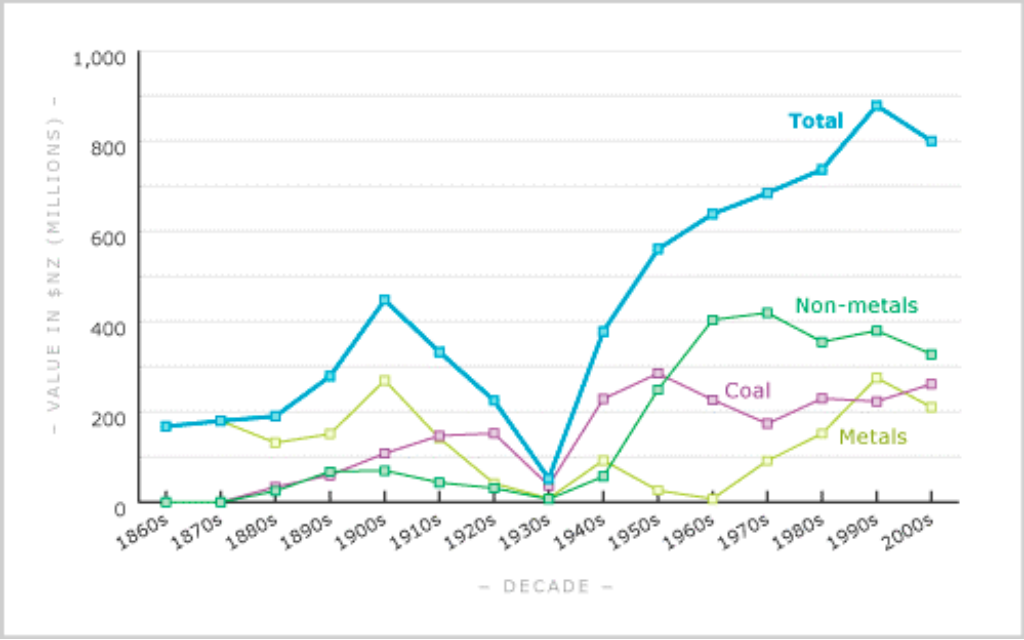
The New Zealand government owns all naturally occurring petroleum [including both oil and gas], radioactive minerals, and gold and silver in New Zealand. Any individual or company wanting to prospect, explore or mine these substances must obtain a permit under the Crown Minerals Act 1991 and pay the specified fees and royalties. The same rules apply to coal and all other metallic and non-metallic minerals and aggregates on Crown-owned land. Mining of minerals and aggregates other than petroleum, radioactive minerals and gold and silver on privately owned land requires the consent of the landowner together with resource consents from local authorities granted under provisions of the Resource Management Act [p 23].

Substantial deposits of coal, gold and industrial minerals are to be found in the region. Coal and gold are of a national and regional economic importance and contribute significantly to the region, and the nations, welfare as a raw material source for local use, employment and export. The West Coast has a range of other minerals present that includes asbestos, pitchblende [a radioactive material], bismuth, beryl, dolomite, corundum and silica. However, it is not economically feasible to mine them all due to the rugged nature of the country in which they are found. Coal and gold are the exception and have been the strength of the West Coast economy for the last hundred years.

There has been a steady increase in the total value of mineral production since 1920 although the proportions of different commodities have changed. In particular, the value of gold production dropped sharply after 1940, but this was more than offset by the rise in production of non-metals.

The graph [Fig 4] shows the value of minerals to the New Zealand economy between 1860 and 2004. Values have been adjusted for inflation to 2004, and have been averaged over five-yearly intervals to minimise the effect of small fluctuations.

Fig. 4. Value of minerals to New Zealand economy 1860-2004.



Source: Annual Parliamentary reports of the Mines Department (later Ministry of Energy, then Crown Minerals, Ministry of Economic Development)

2.5. Mining.

Coal and gold mining have sustained the West Coast community for the last century. Coal went through a decline in the 1960s and 1970s but is now a big industry with millions of tonnes exported per year. The West Coast has the largest reserves of quality coal in New Zealand (MED 2007).

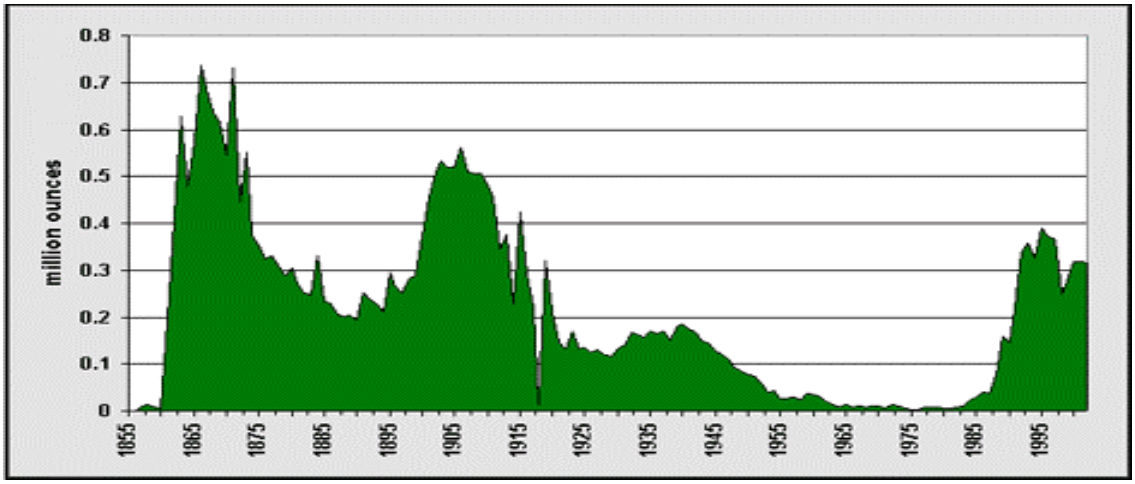
Gold mining in New Zealand dates back to the 1850s, and on the West Coast to 1864. Gold mining on the West Coast has had a long and colourful history and the mining area covered a distance of some 300 kilometres from above the town of Westport in the north, to below the settlement of Okarito in the south. Waiuta is the site of the last and longest worked underground goldmine in the West Coast region being closed in 1951 (Railton & Walter 1990).

The discovery of alluvial gold in 1864 led to the first of a number of gold rushes on the West Coast and was the beginning of the mining industry in the region (May 1962). Gold mining in its various forms and, to a lesser degree coal, was the reason that the “wild and inhospitable country of the West Coast was opened up” (Gordon 1906). Without gold and coal there may well have been no West Coast as it is today. Coal is a major export and brings in wealth and employment to the region in the 21st Century.

The gold industry in New Zealand has gone through boom and bust periods. The West Coast has been part of these. In the 1980s the West Coast enjoyed its last boom, with the Ministry of Economic Development issuing 800 mining licences over 10 years with approximately 100 being worked at any one time. Graph 2 shows there were 735,000 ounces [22 tonne] of gold produced in New Zealand in 1866, a quantity that has not been repeated since. West Coast production would be included in this (MED 2007).

In Fig 5 the graph shows the total gold production in New Zealand 1855 to 1995 and as can be seen in the latter part of the 19th Century, gold of great value was mined.

Fig.5. Total gold production in New Zealand 1855-1995.



Source: Ministry of Economic Development. 2006

The Ministry of Economic Development has estimated the total in-ground [placer [2]] gold reserves of the West Coast at more than 300 tonne, so there is obviously potential for a big increase in production. With the rise in the international gold price it has once again become economically feasible to mine for gold on the West Coast. Gold miners are now starting to actively look for gold and this may be the start of another mini-gold boom. A large international gold miner has reopened an old quartz[3] gold mine out of Reefton where they are open-casting the mine to access the gold bearing quartz from a deep pit. Being a big multi-national company the gold recovery process is a modern, mechanical process that does not use mercury.

2.6. Economy.

The West Coast has a strong tradition of reliance primarily on its natural resources, mainly extractive industries, and great wealth has been taken out of the region. The West Coast has built a diverse secondary industry and service sector base to augment these natural endowments. The current West Coast driver industries include dairying and mining, and it is dependent on the success of these primary industries in the international commodity markets .

[2] Placer is the name for gold-bearing beds of sand and gravel.
[3] Quartz is the most common mineral on the face of the Earth and is a very hard rock with the gold imbedded in it. It requires crushing to release the gold. It is a silicate called silicon dioxide[$SiO_{2]}$]

Chapter 3. Gold.

3.1. The metal.

Gold is an unusual metal because it exists in the earth as the element and not chemically combined with other elements. Silver and copper are the only other metals naturally found in their elemental form. Gold and silver are thought to be the first metals to be worked by humans and have been sought after and treasured since ancient times for wealth and status. Jewellery accounts for approximately 70 percent of the gold demand being extremely profitable at over $44 billion dollars in 2006; making gold Jewellery one of the world's largest categories of consumer goods (Bystrianyk 2007). In times of economic downturn investers hoard gold as a hedge against financial loss – it is seen as a safe investment.

Gold is a relatively rare element, making up only 0.0000004% of the Earth's crust [by mass] and is valuable simply because it is scarce and difficult to extract (Bystrianyk 2007). It is un-reactive and doesn't tarnish like most other metals and is extremely heavy, with a density of 19.4 grams per cubic centimetre [heavier than mercury]. It is this heaviness that plays a crucial part

in many of the physical methods used to extract it from its sources. Gold is the most malleable element known. Just 1 gram of gold, which would be the size of a grain of rice, can be beaten into a thin film covering over 10 square feet [0.93m^2]. Pure gold is an extremely ductile, soft metal that is easy to scratch (World of Chemistry 2007).

3.2. Location of gold.

Gold is often found in underground veins of quartz and, less frequently, in other minerals such as pyrite, granite and mica slate (MED 2007). The veins can be anything from half an inch to several feet wide. There are also large deposits of gold above the ground. Alluvial gold is found as small yellow grains and flakes, or even small nuggets, on the beds of fast-flowing rivers and streams. Due to natural erosion, flooding, glacial movement and weathering, the gold is broken free from its source. Carried downstream by the water, the gold-bearing rock is broken up into small pieces releasing the gold. As it is carried downstream the gold particles become smaller.

Fig. 6. Small gold nuggets.

3.3. Demand.

The demand for gold has fostered gold rushes over the last 2 centuries and still does. Impoverished people in developing countries have turned to small scale gold mining to earn a living. Mercury, because it is easy to use, effective, and generally cheap, is the choice of these miners to extract gold (WHO 1990). The current demand for gold has driven the price from US$260 [NZ$315] per ounce in 2001 to US$725 [NZ$912] per ounce in 2006 (Bystrianyk 2007). Currently the New Zealand price is NZ$1000 as of December 2007. This demand for gold is part of the world wide problem with mercury pollution as millions of people turn to gold extraction as a means of living and use mercury to save the gold (Chemical & Engineering 2007).

3. 4. Modern mining.

The mining industry on the West Coast during the 1980s period was vastly different to the 1880s. Whereas the 19th century was labour intensive, the 20th century used machinery to replace men. In the 1880s when gold mining on the West Coast was at its peak, gold was recovered from the ground by means of panning or sluicing. Under new environmental laws it is no longer acceptable to wash away large swathes of land and leave the environment looking like a World War I battlefield, as happened in the 1880s.

Mining, like other land uses, can cause significant environmental problems. Some past mining practices were highly destructive. For example, dredging in Otago and on the West Coast destroyed large areas of river flats, leaving behind unsightly trails of tailings. Protests and community concerns about the effects of mining have gradually resulted in higher environmental standards. All mining proposals are now evaluated in terms of the Resource Management Act 1991.

The Resource Management Act 1991 and amendments are the major piece of environmental legislation that controls the use of land and the discharge of pollutants to air, land and water, in New Zealand. It has a comprehensive framework for the development and protection of almost all physical and natural features. Mineral extraction is excluded from the sustainability provision of the Act, but as mining invariably involves the use and modification of land, all other parts apply. Territorial authorities [district and regional councils] are responsible for administering the Resource Management Act. Most authorities have incorporated local rules and guidelines for mineral extraction in their district plans.

Mining permits now include requirements to undertake land rehabilitation after mining has been completed. At its best, land that has been mined and rehabilitated is not easily distinguished from land that has never been mined. New Zealand agricultural scientists and engineers have developed considerable expertise in land rehabilitation

Goldmining is part of the West Coast culture and mining today is carried out by small companies employing 5–20 men with most of the small companies consisting of the owner[s] and some employees. Women were not employed in the industry. Modern gold mining involves heavy, tracked excavators and floating, revolving screens, or trommels, [called “floating” because they sit on pontoons that float on the water from the excavated pit]. The heavy, tracked excavators were used to remove the top soils to enable the gold bearing gravels on the bottom[4] to be accessed. These gold bearing gravels are loaded onto the floating screen where the fine gravels and gold are able to be sieved out through mesh and the coarse material moved to waste back into the pit.

The fine gravels, after passing through the screen are passed over riffle boxes / tables [small box channels that have matting on the bottom and small batons laid horizontally to catch the gold]. The principle here is that gold is heavy and will settle out and be caught by the batons and matting whilst the fine gravels and silts, being lighter, will flow away with the water. The water velocity was set so that it carried the majority of the gravels away to waste and the gold, due to its weight can settle out. At the end of the day the “wash up” takes place. This involves picking out any big pieces of gold and then gathering up the fine sands [called” wash dirt” or just “wash”] left over for further treatment.

[4] “Bottom” is the hard area through which the gold can not pass, normally rock / clay .

Fig 7 [p 26] shows a floating screen/ trommel in action on the West Coast. This is a common arrangement on the local gold fields and the machinery was all made locally to suit local conditions. As can be seen they were not labour intensive and could be operated by a minimum of two men. They also require a continuous and large supply of water and this was usually pumped from the pond on which they float and returned to the pond after use. The West Coast has a generous rainfall and numerous rivers so water is not a scarce commodity. The pond was used as a silt trap to prevent the fine silts polluting waterways, a common environmental effect from this industry. In fact water pollution is seen as the major environmental effect from this industry and today is monitored frequently by the Authorities. Chemicals called flocculants are added to the discharge water to help settle out small particles by enabling them to coalesce together into heavier solids that can settle out.

Fig.7. Floating screen/ trommel in action.

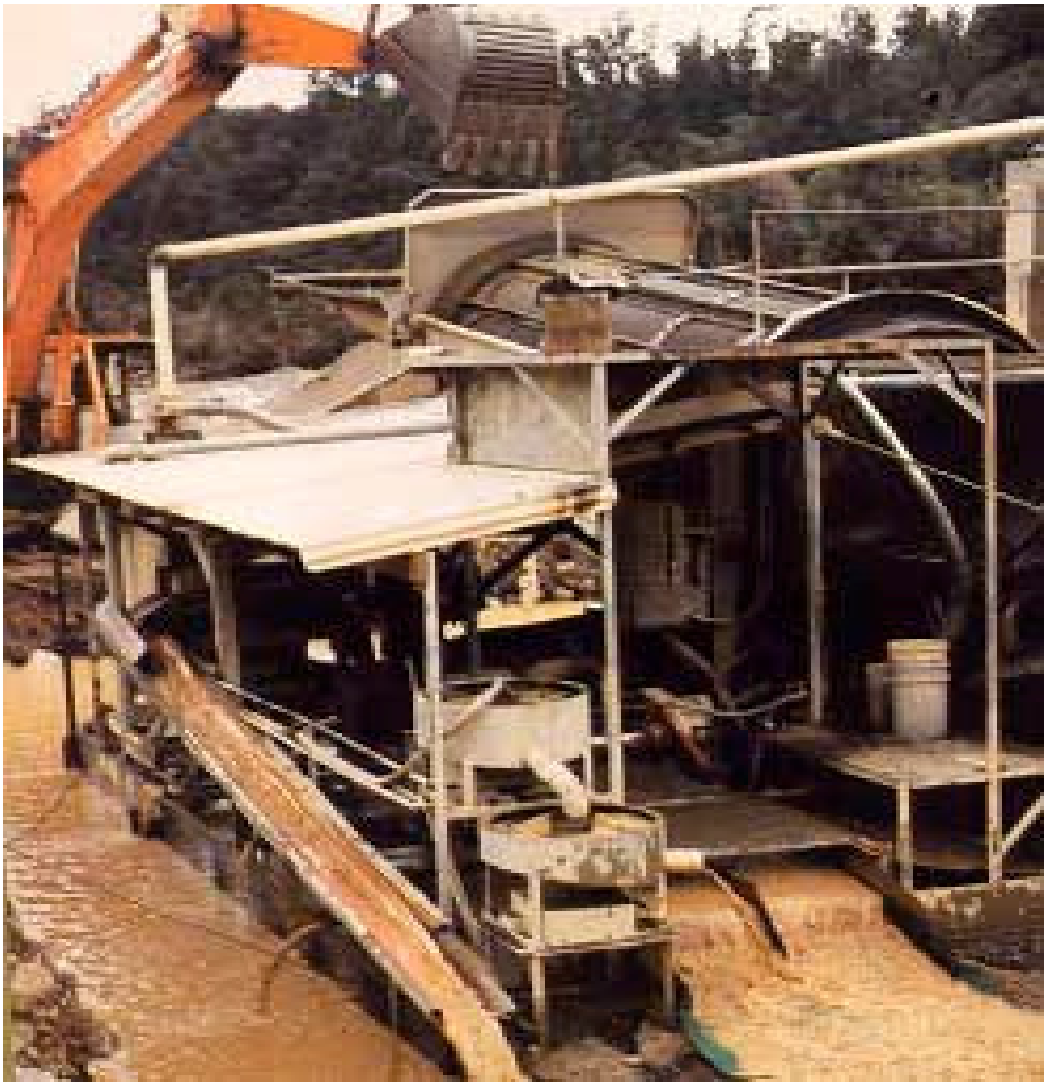
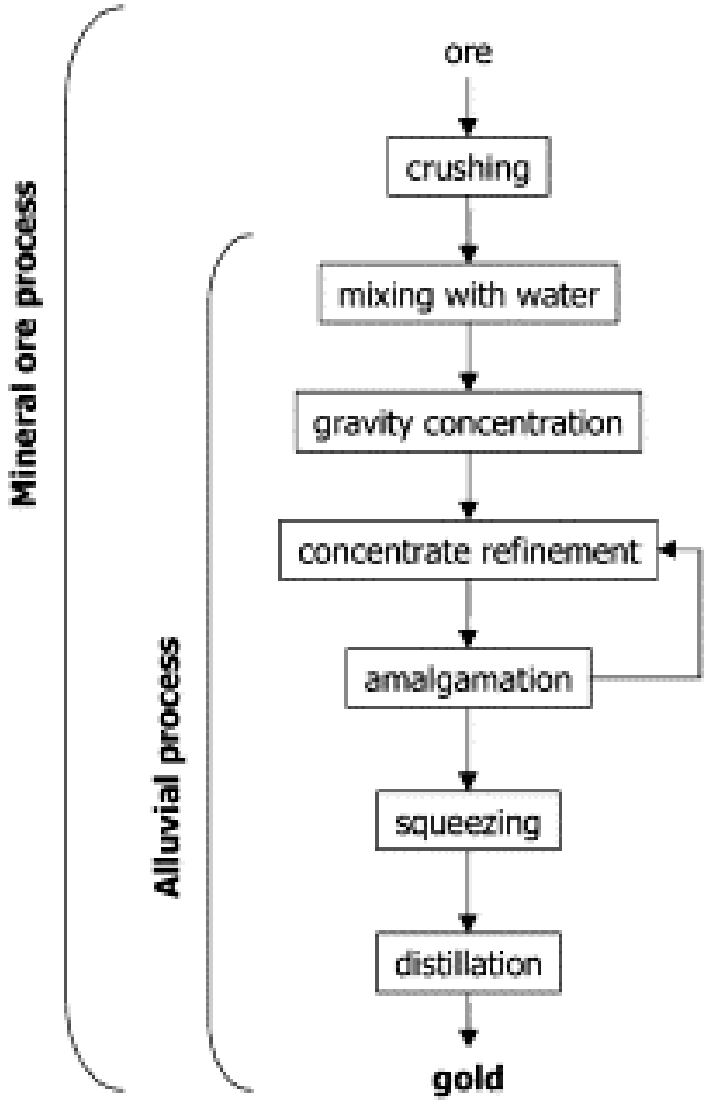


Fig 8 is a flow chart of the processes used in both rock and alluvial mining and shows the process from mining through to the refined or finished gold. The ore crushing stage is not a necessary step in alluvial mining.

Fig 8. Diagram of the stages of the gold mining process.

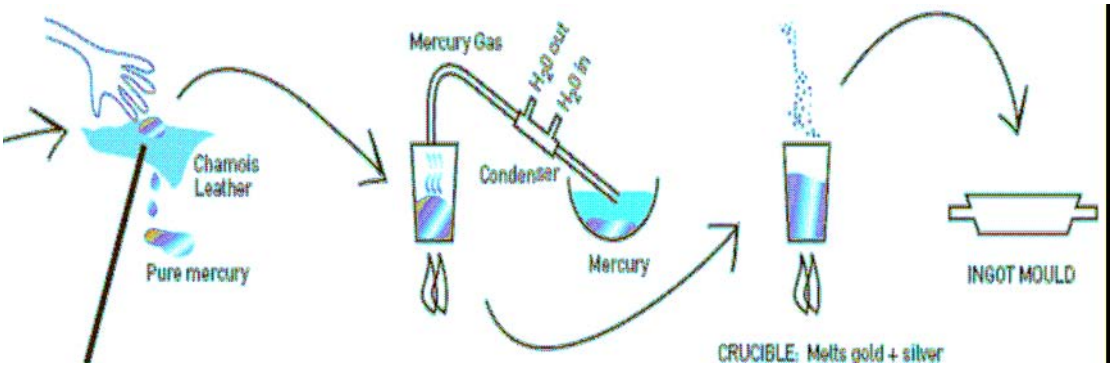


Source: personal paper.

3.5. Treatment of gold wash.

Once the large gold is set aside the “wash” is prepared for amalgamation by separating the sand from the gold in the “wash”. This is achieved in a number of ways, the most common being to put mercury into a pan with the “wash” and, using water, to gradually swirl away the fine sand leaving the gold/mercury mix [amalgam] behind. Another method is to put mercury into a bucket of “wash” and mix with a wide piece of wood. The mercury absorbs the gold and forms an amalgam mass that is squeezed through a cloth, usually a chamois or leather, and the surplus mercury collected. The mass is then transferred to the retort to remove the mercury and free the gold. After retorting the gold is reheated to >1062 ^{0}C [1943 ^{0}F] [melting point of gold] for 30 minutes to ensure that any impurities are removed to give pure gold and poured into moulds. The retorting process is shown in fig 9 below.

Fig 9. Retorting process. Source: personal papers.

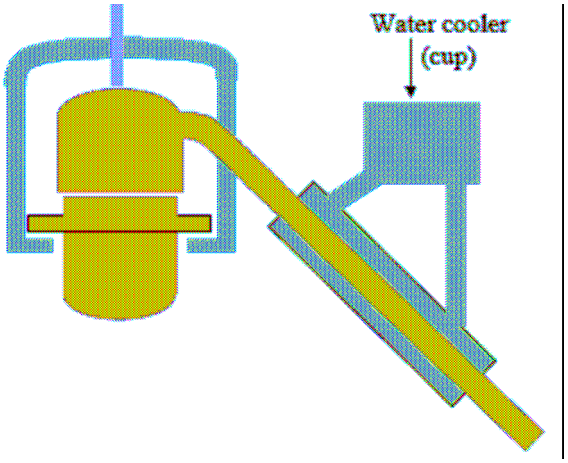


Gold & mercury mix.
Amalgam

3.6. Retort process.

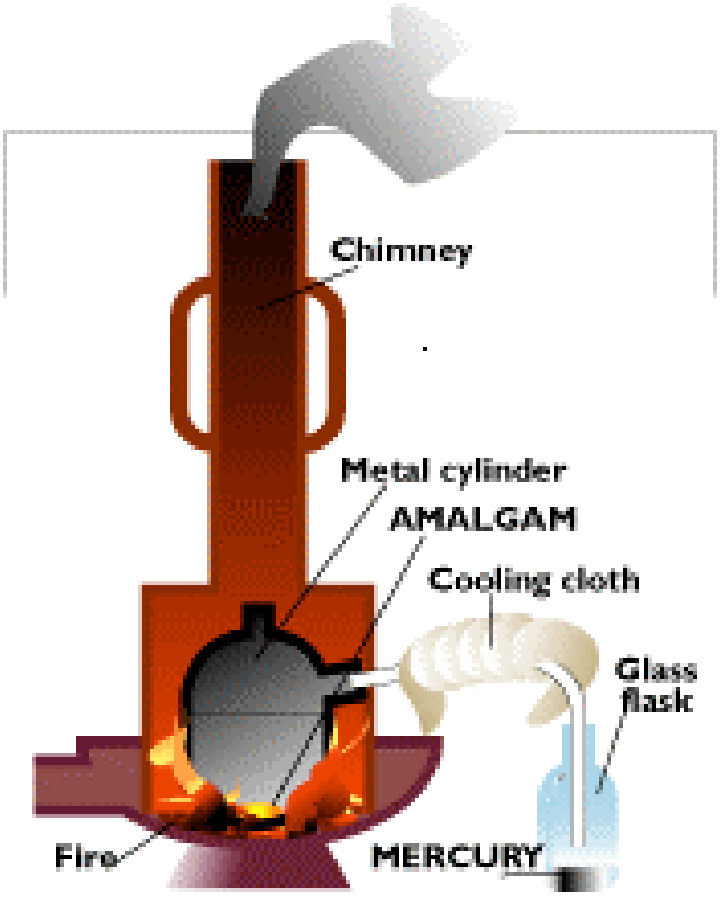
Retorting is a process that has been around as long as the use of mercury in the gold industry. Basically it involves heating the amalgam mass to between 750^0C– 850^0C [1382-1569 ^{0}F] This required the use of specially manufactured retorts of cast iron that consisted of a bottom section into which the amalgam was placed and a top half with a water jacket condenser attached. Once the amalgam was placed the two sections were bolted together with an asbestos or clay seal as shown in fig 10 below.

Fig 10. Diagram of cast iron retort and water jacket. [UNIDO]



This is similar to the type of retort manufactured and used locally on the West Coast. The only difference is that the water cooler shown was replaced by a hose connection from a water supply to the water jacket and the water was run continuously through the jacket during the retort.

Fig 11. Retort in use. Source: personal papers.



Once the amalgam was ready the retort was put into the heating facility where it was positioned over the heat source and the mercury driven off via the water jacket. The outlet of the water jacket was placed into a bucket of water to help condense any vapour that was not condensed by the water jacket. The diagram in fig 11 is an example of a retort in use. There is a slight difference in that the retort used locally would look more like fig 10 [p 29- no cooling cloth used].

After heating the retort is opened, the gold removed for reheating for about 30 minutes to purify it, and poured into ingots where it is marked with the company identification. The mercury is collected for reuse. In most of the small 2–3 man mining companies the retorting and amalgamating are done by the same person

Chapter 4. Mercury.

4.1. History of mercury.

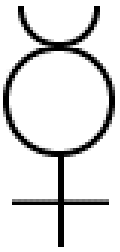
Because they exist in nature in the free state, or as easily decomposable compounds, mercury and the other noble metals [gold & silver] were the first elements to be discovered and utilized by humans. Aristotle discussed the use of 'fluid silver' for religious ceremonies and Hippocrates was said to have used mercury for medicinal purposes. Mercury was considered the basis of metals, close to gold and it was named after the planet Mercurius, which was the planet nearest to the sun [gold]. Others say that because of its mobility it is named after Mercurius, the messenger of the gods in Roman mythology, and that the identification came later (Weeks 1956).

The element mercury has been known for thousands of years and is the only liquid metal. Known in Antiquity by the Chinese and in India, it has been found in Egyptian graves that date from around 1500 BC. The Greek philosopher Theophrastus [372-287BC] described a method for preparing mercury by rubbing cinnabar [Cinnabar is a vermillion–red mineral found in fine granular masses or disseminated through the host rock] with vinegar in a clay dish and he also described a method of distillation that involved heating the cinnabar in an iron shell and collecting the condensation on a convex lid. (Takacs 2000; World of Chemistry 2007).

4.2. Alchemy.

Mercury is the only metal for which the alchemical planetary name became the ordinary name. Its chemical symbol Hg is derived from the Greek word *Hydrargyrum* which means liquid quicksilver and mercury's Alchemy sign is also known as "quicksilver," a reference to its mobility. Mercury is one of the elements which has an alchemical symbol, shown in Fig 12. Speed and mobility were characteristics of the Roman god, Mercury, who served as a messenger to all the other gods and shared his name with the planet nearest the sun.

Fig 12. Alchemical symbol for mercury.



In the ancient art of alchemy, mercury, sulphur, and salt were the Earth's three principle substances. Because they believed that mercury was at the core of all metals, alchemists supposed that gold, silver, copper, tin, lead and iron were all mixtures of mercury and other substances. The central themes to European alchemy was the belief that the correct combination of mercury and other ingredients would yield riches of gold (Goldwater 1972)

4.3. Historical use.

The Romans used their mercury mines as penal institutions for criminals, slaves, and other undesirables. Warders at these mines were among the first to recognize that there was a high likelihood that prisoners would become poisoned and so spare the authorities the need for formal executions. A person put to work in a mine seldom survived more than 3 years (Takacs 2000). Mercury and its compounds have been used in medicine for centuries, and as the toxic effects of mercury and its compounds became more widely known and understood they were no longer considered safe (Goldwater 1972). Mercury was administered to children as a laxative, de-wormer, and teething powder for infants in the early 20th century (EPA.2007).

Mercury has been widely applied in industry and agriculture, as well as in medicine, for centuries. The Romans used vermillion [the red-coloured sulphur salt of mercury] extracted from the Almadén cinnabar mines as a cosmetic and decorative (Nriagu 1979). The history of it's discovery are filled with trial and error methods that are followed by the discovery of its negative side effects. In the fifteenth century mercury was used to treat syphilis and trained physicians continued to prescribe mercury to cure syphilis in the mid-nineteenth century (Syphilis 2007).

A less well documented source of exposure to inorganic mercury among the general population is its use in ethnic, religious, magical, and ritualistic practices and in herbal remedies. The unique properties of elemental mercury or quicksilver have led people to attribute magical and spiritual powers to it through the ages. Mercury has long been used in Chinese herbal preparations and is also used in some Hispanic practices for medical and/or religious reasons, as well as in some Indian ethnic remedies (Kew et al. 1993). Mercury was viewed as an essential component of the alchemical triad of mercury, sulphur, and air and has been associated with the Hindu god Shiva (Little 1997). Elemental mercury is also used in the spiritual practices associated with Santeria, Voodoo, Espiritismo, Palo Mayumbo, and other Afro-Caribbean syncretic religions (EPA 2002).

4.4. Contamination.

Although humans have long put an economic value on metals, it is only recently that they have paid any attention to the health issues. Metals have been, and still are, involved in human, plant and animal health. Most of us will have consumed metals during our lifetime. Many are beneficial but exposure to mercury has a history of causing health problems and the dangers of mercury use were known to people centuries ago. In the 19th century hat making industry workers were exposed to mercury fumes from the felting process and suffered from central nervous system damage giving the phrase

“mad as a hatter”. Most of what we know about mercury poisoning has come from accidental and occuptaional exposure. However, it was not until 1956 that the first official case of mercury affected "disease" was documented in the small fishing village of Minamata on a small island in Japan, which is now referred to as the Minamata Disease. By the time this exposure was brought to world attention the damages, ranging from minor to severe , and from short –term to long-term were already irreversible (EPA 2007).

The Minamata Bay exposure in Japan was a classic exposure from industry discharged waste [containing mercury], into the environment. The Minamata incident is important because it had tragic results and because it was the first documented large scale mercury pollution of the environment. It provided important information on the effects of mercury poisoning and the relationship between the environment and man’s actions. The mercury poisoning [originally called Minamata disease after the city in which it occurred], appeared in the news in the 1970s. Minamata is located on the Western coast of Kyushu, Japan's southernmost island. After World War II Japan was making great efforts to recover from the effects of the war and to become a manufacturing nation. In the rush to achieve its goals environmental considerations were not at the top of the agenda.

In 1932 the Chisso Corporation began to manufacture acetaldehyde, a chemical used to make plastics. Waste from the production process was discharged into the local bay; we now know that the waste contained mercury a by-product of the process. When acetaldehyde was made from acetylene and water, methylmercury was by-produced in the reaction chamber. Methylmercury contaminated the vacuum evapolater, the first still, and even the second still, and was then discharged into the bay. (National Institute for Minamata Diseases 2007).

Though not known until decades later, the heavy metal was converted into methylmercury chloride, an organic form that was able to enter the food chain. Minamata residents relied on fish and shellfish from the bay as a source of protein and these fish were contaminated by the mercury. Unlike elemental mercury, methylmercury can penetrate into mammalian cells because it mimics a common amino acid . It interferes with nerve cell division thereby making prenatal and childhood exposure more damaging than adult exposure (EPA 2001. 2007). After World War II, production of acetaldehyde increased at a rapid pace. As this increase was occurring it was noted that fish began to die and float in Minamata Bay. It was noted at this time that local cats began to show strange behaviour that sometimes resulted in their falling into the sea and drowning (Smith & Smith. 1975).

Kumamoto University reported [Nov. 3, 1956] that the cause of the disease was intoxication caused by eating fish and shellfish contaminated with a kind of heavy metal, but it took a long time to determine the cause of the strange disease as methylmercury poisoning. (Minamata Disease Archives 2007).

The Minamata case is a good example of the ecological consequences of environmental pollution because the effects of the effluent led back to humans. Disasters such as the massive release of methyl isocyanate gas from Union Carbide's plant in Bhopal, India and Chernobyl, concentrates our minds on the human and environmental risks of pollution. However, we do not take the threat posed by low level but more sustained release of chemicals, such as the use worldwide of mercury in the gold recovery industry, as seriously.

Another incident involving mercury occurred in Iraq in 1972 where people were fed bread made from grain treated with an anti-fungal agent containing mercury. Over 400 people died in the weeks that followed (Bakir et al. 1973; EPA 2001).

The toxicity of a chemical is determined by the dose or amount taken into the body. The specific effects further depend on the amount, or concentration, that reaches specific organs such as the brain or kidney that are sensitive to

poisoning by the chemical. Factors that affect the amount of mercury reaching an organ are the rate at which it enters the bloodstream [absorption efficiency] through the skin, the lungs or the gastrointestinal system; the rate at which it is distributed to the different body organs; and changes in its chemical structure that may occur in the different organs due to metabolism (WHO 1991; EPA 2007).

After absorption, the vaporized metallic mercury is excreted in the breath with trace amounts going to urine and faeces. Once transformed to inorganic mercury, excretion is through urine and faeces. After it is absorbed into the body the amount of metallic mercury present is reduced by half every 1-2 months [half-life]. Larger amounts of mercury in the body [body burden] take longer to be removed than smaller amounts. Different organs release accumulated mercury at different rates; brain and kidney have been found to retain mercury for a lifetime. Unsteadiness and tremor when trying to move or to hold objects [intention tremor] and various manifestations of excitability can develop after a long latent period (Ashe 1953; Piikivi et al. 1984; WHO 1991). The assessment of risks due to elemental mercury is based mainly on investigations among exposed humans; therefore the uncertainty of interspecific extrapolation is mostly avoided (WHO 1991).

Chronic exposure to lower levels of mercury vapour affects the central nervous system. Symptoms of chronic poisoning vary, but may include tremors, psychological changes, insomnia, loss of appetite, irritability, headache and short-term memory loss. Mercury has a number of effects on humans, that can be simplified into the following main effects: Disruption of the nervous system; damage to brain functions; DNA damage and chromosomal damage; allergic reactions, resulting in skin rashes, tiredness and headaches; negative reproductive effects, such as sperm damage, birth defects and miscarriages (Roels et al. 1982; Kishi et al. 1993).

4.5. Mercury impact.

Nothing has a higher affinity for mercury than elemental gold. Amalgamation with mercury is one of the oldest methods of extracting gold from its ores. The extraction of silver by amalgamation is generally attributed to the Spanish in Latin America in the late sixteenth century (Takacs 2000). Mercury was known to be used in gold and silver mining since Roman times. The invention of a refining method [the "patio" process] in Spanish colonial America enabled silver and gold to be produced on a large scale in many countries (Takacs 2000). Mercury released to the biosphere due to this ancient activity may have reached over 260,000 metric tons in the period from 1550 to 1930 (UNEP 2005).

An estimated 10 to 15 million small-scale miners rely on mercury to separate grains of gold from small bits of sand and rock using pans or other small scale equipment (UNEP 2005). Michael T. Bender (2007), executive director of the Mercury Policy Project (2007), a group promoting the elimination, reduced use, exposure to, and trade of mercury, stated "up to half these miners have symptoms of mercury poisoning."

According to UNEP (2005) "Mercury is readily available in most countries and relatively inexpensive to obtain. In some cases, it is given for free, contingent on the recovered gold being sold to the mercury provider." This largely unregulated flow of mercury is polluting waterways, land, and the miners themselves throughout Africa, South America, and Asia. UNEP (2007) estimated that small-scale gold mining released between 650 and 1,000 metric tons of mercury per year, and that this pollution accounts for about one third of all mercury released to the environment from human activities. It is found in mine tailings, soil, plants, sediments, waterways and around mine plants & machinery. Scoullos et al. (2000) stated that in the early 1990's it was estimated that at least 95 % of mercury used was lost to the environment, where it contributed to the continuing global atmospheric re-mobilisation and cycling of mercury.

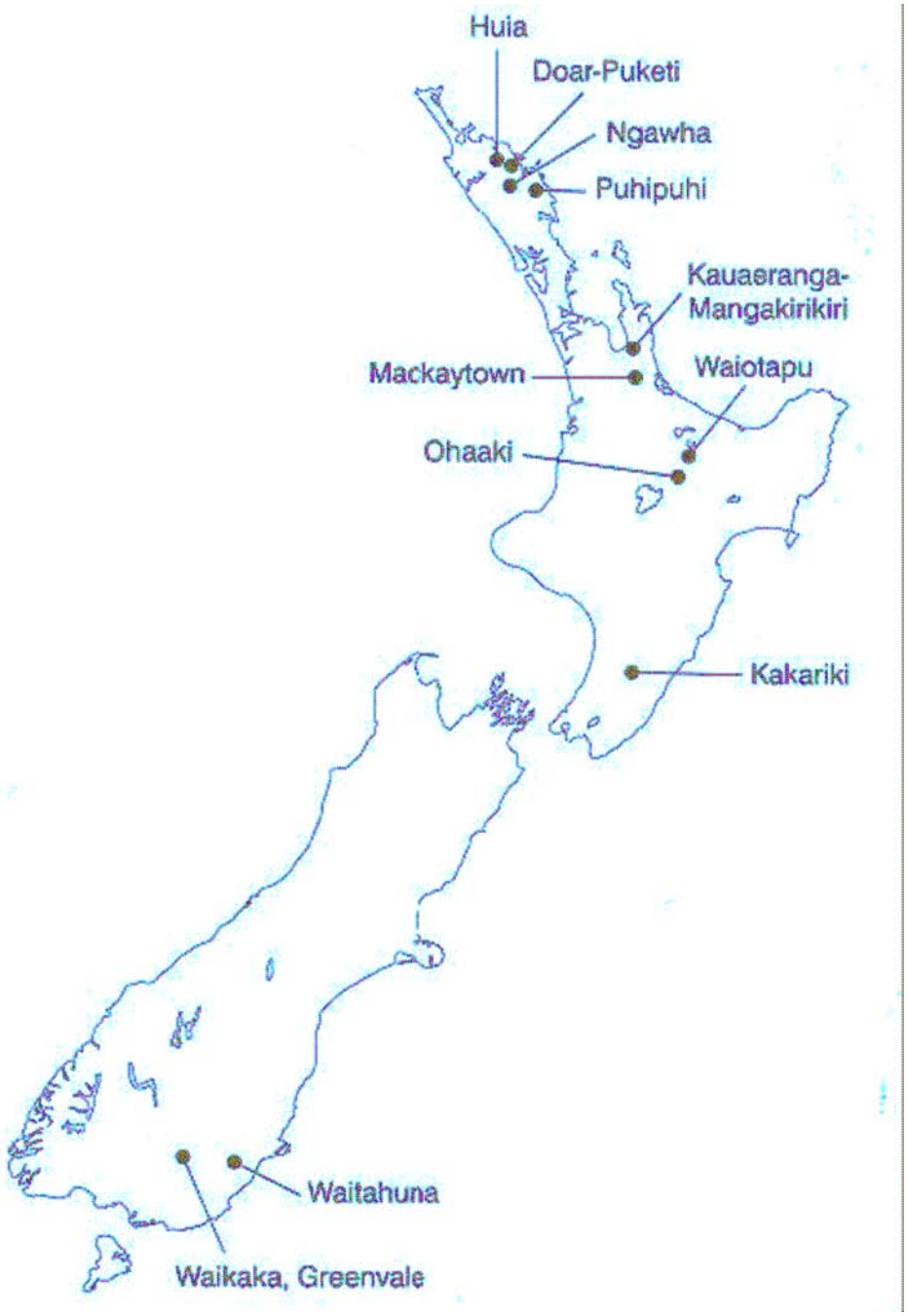
The optimal mercury to gold ratio [Hg:Au] when using mercury to save gold is about 1 v/v, but greater quantities are often added to ensure that all available gold is amalgamated. In some areas of Brazil, for example, the Hg:Au ratio is estimated to range between 1.32 and 2.0 (Bidone et al. 1997). Some researchers argue that the official figure of 1.32 is an underestimation, and that ratios as high as 6.0 or even 10.0 are more realistic estimations (Malm et al.1990).

Mercury has been mined in New Zealand as shown in fig 13 [p 42] (Henderson 1922; Williams 1974; Brathwaite & Pirajno 1993). The main mercury deposits are found in sinters[5], lakebeds and volcanic and sedimentary rocks associated with extinct and active hot springs at Huia, Puketi, Puhipuhi and Ngawha in Northland and Mackaytown on the Coromandel Peninsula (Officers of the New Zealand Geological Survey 1970). Mercury minerals found in New Zealand include: cinnabar, coloradoite[6], livingstonite, metacinnabar and native mercury (Railton & Watters 1990).

[5] Sinters - When hot springs overflow they often form layers of sinter – a rock made of very fine-grained silica – that takes the form of flats, terraces and mounds.

[6] Coloradoite is a mineral consisting of the compound mercury telluride (HgTe) .

Fig 13. Map of mercury ore sources in New Zealand.



Source: Railton & Watters 1990.

4.6. Mercury uses.

Liquid at room temperature, mercury is a good electrical conductor with high density and surface tension and is able to expand and contract uniformly over its entire liquid range in response to changes in pressure and temperature. Being toxic to micro-organisms [including pathogenic organisms] and other pests, mercury is an excellent material for many agricultural purposes.

The use to which mercury and mercury containing compounds can be put is considerable. It is widely used in barometers, thermometers, hydrometers, and pyrometers. It is used in mercury arc lamps producing ultraviolet rays and in fluorescent lamps. The mercury dry-cell battery developed during World War II led to the extensive use of the metal in alkaline batteries until recently.

Mercury was essential to the development of the incandescent lamp by Thomas Edison and remains a principal component of fluorescent light fixtures (Carpi 1997). It is used as a catalyst in oxidation of organic compounds, extracting gold and silver from ores, electric rectifiers, and as a cathode in electrolysis. It is also used in pulp and paper manufacturing, batteries, amalgams [dental preparations], lubricants, caustic soda, chlorine, and in the manufacture of switching devices such as oscillators. The agricultural chemical industries have used it to treat seeds, and antifouling paints use its properties to prevent growth on boat hulls. (ACGIH 1991).

Compounds of mercury are used for:

- Fungicides
- Pharmaceuticals e.g. black mercurous oxide [Hg_2O] is used in skin ointments and Mercurochrome [$C_{20}H_8O_6Na_2Br_2Hg$], a green crystalline powder that turns to a brilliant red when dissolved in water is used as an antiseptic
- Paint pigments e.g. Mercury sulphide [HgS] is a brilliant red pigment.
- Explosives.
- Mercuric chloride [$HgCl_2$] an extremely poisonous white crystalline powder, water and alcohol soluble, used as a wood preservative, insecticide, rat poison, in tanning, and as a caustic antiseptic in medicine.

The predominant use of mercury in pre-industrial times was for the extraction and purification of gold and silver because of its affinity for those precious metals (Farrar & Williams 1977). Greenpeace (1994) estimated the total world-wide consumption of mercury for gold mining at 400-500 metric tons/year in 1993-94. This estimate was considered too high by some in the industry and too low by others, with suggestions that 500 to 1000 metric tons annually may be consumed by gold and silver miners with a very high percentage lost to the environment, (MMSD 2007).

Small-scale or artisanal[7] mining for gold is a world-wide phenomenon, which directly and indirectly supports in excess of 100 million people. 50 years ago, mercury was not utilised in artisanal gold extraction and only began some 25 years ago when it became too difficult to extract gold from rocks (WHO 1990).

Millions of people have become artisanal miners, despite the risks of working in small tunnels or on steep hills and being exposed to mercury spilling mills, toxic vapours and explosives. The worldwide demand for gold is presently high, 44 percent above the total annual production of the world's gold mines. In South America, over a million people are directly involved in small-scale gold mining operations. If Africa and Asia are also considered, there could be as many as six million artisanal miners worldwide, women among them (UNIDO 2002).

[7] A recently coined word to describe small itinerant miners in Asia and Latin America.

4. 7. Mercury properties.

4.7.1 The metal.

Mercury is a rare transition metal and the only pure metal that is liquid at room temperature. It is classified as a heavy metal. The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations (MMSD 2002 accessed 2007). They are natural components of the Earth's crust that cannot be degraded or destroyed (Goldwater 1972). Once mercury has been liberated from ores, fossil fuel or mineral deposits and released into the biosphere, it can be highly mobile, cycling between the earth's surface and the atmosphere (WHO 1991; UNEP 2002).

4.7.2. Chemical properties.

Metallic mercury [Hg^0] can be changed to positively charged inorganic forms Hg^+ ands Hg^{2+} as a result of a chemical process known as oxidation (Lindberg 2001). Inorganic forms of mercury can be changed to metallic mercury by a process called reduction or can be combined with a carbon atom [as the carbon in a methyl group - CH_3] to form organic mercury compounds (Farrar 1977). Organic mercury compounds can themselves be metabolized so that the carbon is removed from the mercury. Mercury can be bound to other compounds as monovalent Hg^+ or divalent mercury Hg^{2+} (NAS 1978). Many inorganic and organic compounds of mercury can be formed from Hg^{2+}.

Table 1. Vapour pressure-saturation concentration of metallic mercury at various temperatures . [Source: OSHA 2007].

Temperature		Vapour Pressure	Mercury Concentration
℃	℉	(torr)	(µg/m^3)
0	32.0	0.000185	2,180
10	50.0	0.000490	5,880
20	68.0	0.001201	13,200
24	75.2	0.001691	18,300
28	82.4	0.002359	25,200
30	86.0	0.002777	29,500
32	89.6	0.003261	34,400
36	96.8	0.004471	46,600
40	104.0	0.006079	62,600

4.7.3. Occurrence.

In pure form it is known alternatively as “elemental” or “metallic” mercury [expressed as Hg^0] however it is rarely found in nature as the pure, liquid metal (EPA 1997; Agency 1999). Elemental mercury in the atmosphere can undergo transformation into inorganic mercury forms, providing a significant pathway for deposition (WHO 1991; Carpi 1997; UNEP 2005).

Mercury is a rather poor conductor of heat if compared with other metals but it is a fair conductor of electricity. As already stated it alloys easily with many metals, such as gold, silver, and tin which is why it is used so extensively to save gold. (Takacs 2000).

4.7.4. Chemical state.

Being an element, mercury cannot be broken down or degraded into harmless substances (EPA 1997; Lacerda 1997). Several forms of mercury occur naturally in the environment. and the most common forms of mercury found are metallic mercury [Hg], mercuric sulphide [HgS], mercuric chloride [$HgCl_2$] and methylmercury [$HgCH_3$]. Some microorganisms and natural processes can change the mercury from one form to another (EPA 1997). Mercury is released into the atmosphere from natural sources such as volcanoes and off-gassing from the earth's crust, etc. (EPA 1996; UNEP 2002).

Mercury exists in the following main states under natural conditions:
(WHO 1991; EPA 1996).

- As metallic vapour and liquid/elemental mercury
- Bound in mercury containing minerals [solid]; e.g. coal
- As ions in solution or bound in ionic compounds [inorganic and organic salts];
- As soluble ion complexes;
- As gaseous or dissolved non-ionic organic compounds
- Bound to inorganic or organic particles/matter by ionic, electrophilic or lipophilic adsorption.

4.8. Production of mercury.

4.8.1. Source.

Mercury is a natural component of the earth, with an average abundance of approximately 0.05 mg/kg in the Earth's crust, with significant local variations. World production of mercury is about 8000 tonnes / year and reserves are thought to be about 600,000 tonnes (EPA 1997). Spain and Italy are the traditional sources of mercury (World of Chemistry 2007). The Spanish mines at Almadén and the Italian [now Slovenian] mines at Idria have been worked continuously since Roman times (Goldwater 1972).

Mercury ores that are mined generally contain about 1% mercury, although the strata mined in Spain typically contain up to 12-14% mercury. There are 25 principal mercury minerals known but the only deposits that have been harvested for the extraction of mercury are cinnabar [HgS] (WHO 1991).

4.8.2. Process.

The most economical way to produce mercury is to roast the ore with lime [CaO], or iron metal [Fe], or air [O_2], which oxidizes the sulphur to [SO_2] or [FeS], and volatilizes the mercury, which is then condensed and collected. The reaction begins at about 250°C [482^0F] and is complete by 800°C [1472^0F]. The metal is usually extracted by heating cinnabar in a current of air and condensing the vapour.

The equation for this extraction is:

$$HgS + O_2 \rightarrow Hg + SO_2$$

Because cinnabar ore is relatively concentrated, it can be processed directly without any intermediate steps to remove waste material.

The first step is to roast the ore:

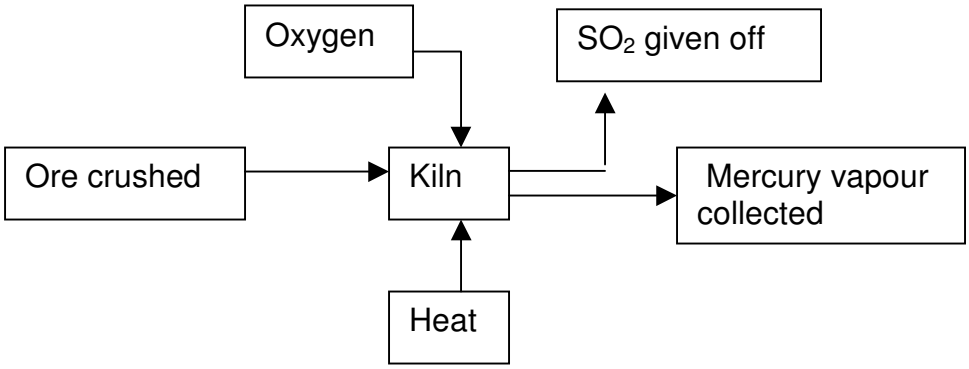
- The ore is first crushed in a cone crusher.
- The crushed ore is then ground even smaller by a series of mills.
- The finely powdered ore is fed into a furnace or kiln to be heated.
- Heat is provided in the lower portion of the furnace or kiln.
- The heated cinnabar [HgS] reacts with the oxygen [0_2] in the air to produce sulphur dioxide [SO_2], allowing the mercury to rise as a vapour.

The next stage is to condense the mercury:

- The mercury vapour rises up and out of the furnace or kiln along with the sulphur dioxide, water vapour, and other products of combustion.
- The hot furnace exhaust passes through a water-cooled condenser. As the exhaust cools, the mercury with a boiling point of 357°C, [675°F] is the first to condense into a liquid, leaving the other gases and vapours to be vented or to be processed further to reduce air pollution.
- The liquid mercury is collected. Because mercury has a very high specific gravity, any impurities tend to rise to the surface and form a dark film or scum.
- These impurities are removed by filtration, leaving liquid mercury that is about 99.9% pure. The impurities are treated with lime to separate and capture any mercury, which may have formed compounds (Stwertka 1996).

Fig 14. Diagram of mercury production process stages from crushing of cinnabar to the collection of vapour.

[Author's diagram]



Because it has a very simple metallurgy mercury can be purified by distillation. Mercury is sold in iron flasks [it does not react with iron] holding 34.5 kg [76 lb] and a volume of about 2.5 litres. Industrial mercury is 99.9% pure (Goldwater 1972). Despite its record mercury is an essential element in industry although its decline in use in developed nations may continue. Developing countries without stringent environmental controls continue to use it e.g. China and India, and it is known that gold recovery is still carried on in China and South America by small scale miners [Artisanal].

Chapter 5. Toxicity.

5.1. Hazard.

It was in the mining of the element that mercury first became associated with human illness (Goldwater 1972). Mr. John Welsh, a Mines Inspector with Worksafe Australia {Australian Government department] in 1976, reported that many miners in Australia were still using mercury in their gold saving processes and some had been doing so for 40 years. He stated that he had noticed a number of health problems associated with them including loss of teeth, lethargy and similar problems to those listed in symptoms of mercury poisoning (personal correspondence).

Mercury is of significant concern as an environmental pollutant that can bio-accumulate [*an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment*]. It can enter our bodies via food, drinking water and air. As trace elements, some heavy metals are essential to maintain the metabolism of the human body, but at higher concentrations they can have a detrimental effect. Mercury has no known biological function to human biochemistry or physiology and does not occur naturally in living organisms (EPA 1997).

For adults, mercury poisoning is usually [but not always] a reversible problem. The body can rid itself of mercury if the exposure to mercury is halted. However, for children and developing fetuses, mercury poisoning can cause long-term neurological problems. Mercury exposure before birth has been linked to lower intelligence and delays in learning motor skills (WHO 1990; EPA 1997).

5.2. Psychological effects.

Excitability and tremors are results of the deposition of mercury in the nervous system (Barragard 1991). There is a rapid transfer of the vaporized form from blood to the brain; transformation of metallic mercury to the inorganic form in the brain results in accumulation (Bluhm et al. 1992). Both forms may be toxic in the brain. Unsteadiness and tremor when trying to move or to hold objects [intention tremor] and various manifestations of excitability can develop after a long latent period (Roels et al. 1982).

Damaged brain functions can cause degradation of learning abilities, personality changes, tremors, vision changes, deafness, muscle un-coordination and memory loss (Piikivi & Tolonen 1989). Limited information from deceased miners showed mercury concentrations in the brain, years after cessation of exposure, of several mg/kg, with still higher values in some parts of the brain (Kishi et al. 1993).

Compounds accumulate in living things any time they are taken up and stored faster than they are broken down [metabolised] or excreted. Metals have played an important role in medicine for years throughout history and, as already noted, many are essential in our diets in varying quantities, although people have only recently realised their significance. This could probably be attributed to our increased awareness of personal and family health. However, at the other extreme, certain metals which can enter the body via a variety of routes are toxic, even in trace amounts, leading to toxicity (Goldwater 1972). Because it is a neurotoxin[8] it is highly toxic to humans, animals, and the environment (Piotrowski et al. 1975; WHO 1990).

The form in which mercury occurs determines how toxic it is. Inhalation of elemental mercury vapours is one of the main causes of toxicity in humans, as mercury is well absorbed by the lungs. To develop problems by inhalation you need either a large one-time exposure or a long-term exposure (Hursh et al. 1976).

5.3. Dose.

The toxicity of a chemical is determined by the dose or amount taken into the body and the specific effects depend on the amount or concentration that

[8] A neurotoxin is a toxin that acts specifically on nerve cells called neurons.

reaches the organs that are sensitive to the chemical e.g. brain and kidneys (Piiviki et al. 1989; Kishi et al. 1993). The dose needed to bring about a definite undesirable result on a body differs from person to person. Toxicity assessment is made difficult by biological variation. Ethically we can not carry out objective tests on humans so the best methods available rely on observing the results of accidents and animal experimentation. Because humans will not necessarily show the same reactions as animals we have to be very careful when extrapolating from animal experiments. In the case of metallic mercury we are interested in the concentration [LC_{50}] due to the vapour being the main risk factor. The TLV in New Zealand for mercury is a time weighted average [TWA] of 0.05 mg/m^3 (OSH 1994), this is below the US figure of 1.0 mg/m^3 (OSHA 2007). There is no short term exposure level [STEL] for mercury in New Zealand.

5.4. Body burden.

The general population is primarily exposed to mercury through the diet and dental amalgam. WHO (1976) estimated that in industrial countries about 3% of the total consumption of mercury was used for dental amalgam. Mercury amalgam has been used extensively as a tooth - filling material for more than 150 years and accounts for 75-80% of all single tooth restorations (Bauer & First 1982; Wolff et al. 1983).

Factors that affect the amount of mercury reaching an organ are the rate at which it enters the bloodstream; the rate at which it is distributed to the different body organs; and changes in its chemical structure that may occur in the different organs due to metabolism (Piotrowski et al. 1975). Other chemicals in the body can alter the rate of transformation from metallic mercury to inorganic mercury and the distribution to different body organs (WHO 1990). Mercury distributes to all tissues and reaches peak levels within 24 hours, except in the brain, where peak levels are achieved within 23 days (Hursh et al. 1976)

Methylmercury incorporated into biological tissues is most toxic to humans. The concentration of CH_3Hg generally increases with each step up the food chain. Therefore, even though the concentrations in water may be very low and deemed safe for human consumption as drinking water, the concentration levels in food, especially fish, may reach levels that are considered potentially harmful to humans. In New Zealand the levels for mercury in food is 0.5mg/kg (NZFSA 2006) and in water, 2 mg/L (DW guidelines 2005).

5.5. Absorption.

When inhaled, about 80 percent of elemental mercury is absorbed into the blood stream through the alveoli (Kishi 1993). When ingested, only a small amount [0.01%] is absorbed through the gastrointestinal tract, making toxicity from this route rare (Hursh et al. 1976). Dermal absorption also is negligible.

Mercury exists in several different forms that can be changed to others and these different forms have an effect on how they are absorbed (WHO 1991).

The charge and chemical form of mercury affect how it is absorbed and transported in the body (WHO 1991). Uncharged mercury can move into cells readily (Piikivi et al. 1989). In the body, conversion to the charged, inorganic form predominates but other transformations can occur (Ashe 1953). In contrast, metallic and organic mercury can more readily cause brain damage since they can pass through the protective blood-brain barrier (Piikivi et al. 1989). These compounds can also cause kidney toxicity in part because they are readily transformed to inorganic mercury in the body (NAS 1978). Organic mercury compounds can accumulate in living organisms such as fish [part of the food chain] (WHO 1991). The kidneys eventually accumulate a major proportion of the total body burden due to their rich blood supply (Roels et al. 1982).

Table 2. Absorption of metallic mercury by route of contact.

Source: WHO 1991.

Ingestion	Dermal contact	Inhalation
Low for liquid form	Moderate for vapour	High for vapour

Although elemental mercury dissolves in the blood upon inhalation some remains unchanged and may remain in plasma where it can be transported to organs such as the brain (Clarkson 1989). It may also enter red blood cells, where it is readily transformed to the inorganic form. Inorganic mercury can either return to the blood plasma and combine with carrier proteins there or remain in the red blood cell (Halbach & Clarkson 1978) Once inhaled into the lungs, elemental mercury vapours rapidly enter the bloodstream and dissolved vapour can undergo rapid oxidation (Clarkson 1989).

5.6. Carcinogenicity.

The effects of elemental mercury on the central nervous system have been extensively studied. However, much less is known, from either humans or experimental animals, of its reproductive toxicity, genotoxicity, or carcinogenicity; the limited information that is available would tend to indicate that such effects are unlikely at exposure levels that do not cause central nervous system effects. Most of the studies rely on assessment of exposure at the time of study, which may not be fully informative, as mercury has a long half-life in the body and thus accumulates in continuous exposure. Furthermore, it is possible that the exposure has decreased over time, and thus the exposure measured at the time of the study may represent an underestimate. However, the few studies that have measured data on exposure over long periods of time yield very similar results, despite having only a single point estimate of the exposure (Seigneur et al. 2004).

In 1993, IARC evaluated metallic mercury and inorganic mercury compounds and found that there was inadequate evidence in experimental animals to show carcinogenicity of metallic mercury. Pirrone et al. (2001) cited a number of studies of occupational mercury exposure, including studies done after the IARC evaluation in 1993, and concluded that lung cancer is the only cancer form, which seems to have consistently increased among various groups of workers exposed to metallic and inorganic mercury. WHO (1991) reported that while carcinogenicity and mutagenicity are not commonly associated with mercury exposure. Mercury can cross the placental barrier where exposure can lead to spontaneous abortion, congenital malformations and severe neurological defects such as cerebral palsy (WHO 1991).

5.7. Dermal.

Direct contact of the skin with mercury can lead to dermatitis. Dermal absorption of elemental mercury is limited and Hursh et al. (1989) estimated that dermal absorption contributes approximately 2.6% of absorbed mercury. Exposure to elemental mercury vapours for acute or intermediate duration can result in a response known as acrodynia or "pink disease" (Schwartz et al. 1992). This is characterized by peeling hands and soles of feet, excessive perspiration, itching, rash, joint pain and weakness, elevated blood pressure and tachycardia (Bluhm et al. 1992). Rash and stomatitis have been reported after high inhalation exposures (Barregard et al. 1996).

5.8. Excretion.

Elimination of mercury occurs primarily through the urine and faeces, with expired air, sweat, and saliva contributing to a much lesser extent (EPA 2007). Urine and faeces are the main excretory pathways in humans, with an absorbed dose half-life of approximately 1– 2 months (Clarkson 1989). After a short-term high-level mercury exposure in humans, urinary excretion accounts for 13% of the total body burden. After long-term exposure, urinary excretion increases to 58% (Hursh et al. 1976). Exhalation through the lungs and secretion in saliva, bile, and sweat may also contribute a small portion to the excretion process (Joselow et al. 1968).

Table 3. Estimated average daily intake and retention [µg/day] of total metallic mercury in the general American population not occupationally exposed to mercury.

Exposure	Elemental mercury vapour
Air Food Fish Non – fish Drinking water Dental amalgams	0.03 [0.024] 0 0 0 3.8 – 21 [3 – 17]
Total	3.9 – 21 [3.1 17]

Table 3 from: Environmental Health Criteria 101: Methyl mercury (WHO 1990). Values given are the estimated average daily intake; the figures in parentheses represent the estimated amount retained in the body of an adult.

5.9. Acute poisoning.

Many reports of acute poisonings in both adults and children after various exposure scenarios have been, and continue to be, published (ATSDR, 1999). However, only a limited number of reports that have information on the dose or exposure levels are available.

5.9.1. Mercury poisoning cases.

A case involved mercury poisoning in a family of four after an in-home smelting operation involving the freeing of gold from amalgam by one of the family members. Two of the victims exhibited shortness of breath, malaise, nausea, vomiting, and diarrhoea within 24 hours of exposure. Three days after exposure, the patients, [one male, one female] showed signs of adult respiratory distress syndrome. On day 5, chelation therapy was begun. One of the patients died on day 7 and the other on day 9 from cerebral oedema. Two other victims, a woman and a man, died from cardiac arrest after 21 and 23 days, respectively. The serum and urinary mercury levels prior to chelation therapy for the woman were 3.2 and 34 nmol/litre, respectively. The blood and urinary levels of mercury for the man prior to chelation were 4.0 and 105 nmol/litre respectively, (Gottlieb & Kanuluen, 1991).

The author was involved in a case where a teacher broke a thermometer in his car and the mercury became dispersed inside. He continued to drive the

car in the winter with heater on and windows up. He became unwell and was lethargic. Eventually his doctor took a blood test that revealed high blood mercury levels. On measurement his car was found to have mercury vapour levels of 0.7 mg/m^3. Once the car was decontaminated his symptoms disappeared.

An occupational case involved a 29-year-old male who was employed for 5 years in a lamp socket manufacturing facility in Taiwan. His pre-treatment urinary and blood mercury concentrations were 610 µg/litre and 23.7 µg/dl, respectively. The man displayed a variety of symptoms, including blurred vision, dysarthria[9], prominent gingivitis[10], tremor (usually postural and intentional), unsteady gait, and slow mental response. The time-weighted average (TWA) concentration of mercury in the air in the room where this individual spent most of his working time during his employment was 0.945 mg/m^3. A 27-year-old female who had been on the job in the same Taiwanese lamp socket manufacturing facility for 1.5 years also showed a variety of symptoms, including gum pain, dizziness, poor attention, bad temper, some numbness, hypersalivation, hyperhidrosis, and fatigue. This individual, whose work had been primarily in a room having a TWA mercury air concentration of 0.709 mg/m^3, had initial urinary and blood mercury levels of 408 µg/litre and 10.5 µg/dl, respectively, but did not require chelation. Her symptoms abated fully approximately 2 months following discontinuation of exposure (Yang et al. 1994).

[9] Dysarthria - the term used to describe difficulty with speech production.

[10] Gingivitis – is an inflammation of the gums – the initial stage of gum disease.

Chapter 6. Environment.

6.1 General.

It is well known that there are large areas of the world where there are naturally elevated levels of trace metals that have resulted in metal excesses and chronic poisoning in people / animals that live in the area (Scoullos et al. 2000; UNEP 2002). Man's use of the earth's resources has been very inefficient and wasteful. Through a lack of knowledge, and in some cases a lack of care, he has contaminated the environment with industrial waste in the rush to make money and exploit those resources. Environmental pollution is increased by this attitude, and a combination of man made and natural mercury releases to the environment has resulted in high levels of contamination of land, water, air and food.

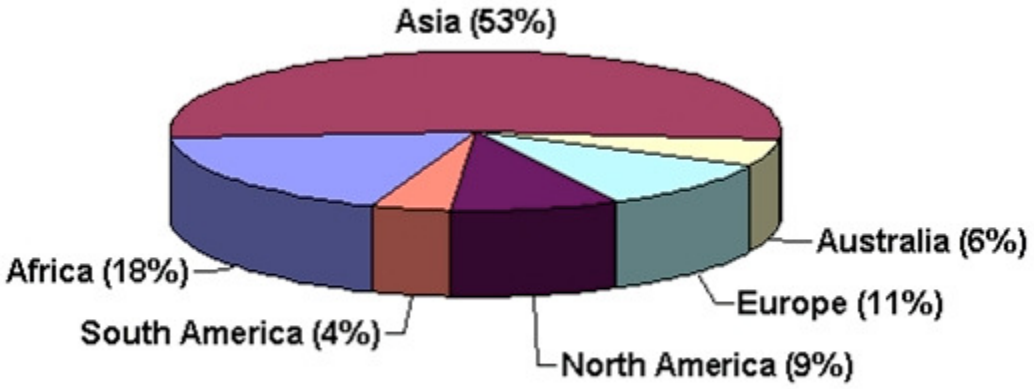
6.2. Airborne mercury.

Mercury in the air eventually ends up in rivers and lakes where it can be readily taken up into the food chain. Lacerda (1997) estimated the yearly global releases of mercury to the environment from gold extraction at up to 460 metric tonnes / year in the late 1980's and early 1990's, being equivalent to about 10 % of total global anthropogenic releases. Mercury is present at very low levels throughout the biosphere and its absorption by plants may

account for the presence of mercury within fossil fuels like coal, oil and gas (WHO 1990; NTIS 2007). Nearer to New Zealand, Dhindsa et al. (2003) estimated that 1903 tonnes of mercury was released to the environment at Gympie in Queensland, Australia during 60 years of gold mining and, of that, 1236 tonnes were released into the air.

Recent estimates, which are highly uncertain, of annual total global mercury emissions from all sources, natural and anthropogenic, are about 4,400 to 7,500 metric tonnes emitted per year. Fig 15 below provides information about the worldwide distribution of mercury emissions.

Fig 15.



Source: Presentation by J. Pacyna and J. Munthe at mercury workshop in Brussels, March 29-30, 2004 quoted by USEPA mercury emissions: The global context .

6.3. Mercury as a pollutant.

Mercury is a global pollutant with complex and unusual chemical and physical properties. The major natural source of mercury is the degassing of the Earth's crust, emissions from volcanoes and evaporation from natural bodies of water. The non–natural causes are man made.

Mercury is mostly present in the atmosphere in a relatively unreactive form as a gaseous element (WHO 1991). The long atmospheric lifetime of its gaseous form means the emission, transport and deposition of mercury is a global issue (Lacerda 1997). Once in the environment, mercury is persistent, it never goes away and mercury vapour is converted to soluble forms and deposited by rain onto soil and water. The atmospheric residence time for mercury vapour is up to 3 years, whereas soluble forms have a residence time of only a few weeks (WHO 1990). Mercury will bioaccumulate and increase the concentration in the environment and any biological organism exposed to that environment over time (Heiserman 1992). Mercury occurs in three valence states in nature: elemental mercury [metallic, Hg^{o}], monovalent mercury [mercurous, Hg_2^{+2}] and divalent mercury [mercuric, Hg^{2+}]. Of the two ionized states, monovalent and divalent mercury, the latter is more stable and more common in the environment (NAS 1978).

The earth's surface soils, water bodies and bottom sediments are thought to be the primary biospheric sinks for mercury (UNEP 2002). The adsorption of mercury to soil is dependent upon the organic content of the particular soil or sediment (Blume & Brummer 1991).

6.4. Mining.

Gold mining is a source of mercury discharge to the environment as well as being a source of harm to the health of the handlers. Mercury that is not inhaled or washed away during the amalgamation process settles into the surrounding environment, where it is absorbed and processed by a variety of living organisms, this process transforms elemental mercury into methyl mercury, one of the most toxic organic compounds and a powerful neurotoxin and food chain bioaccumulator (UNEP 2005). Approximately 95% of all mercury used in small-scale gold mining is released into the environment, constituting a danger on all fronts - economic, environmental and human health (EPA 1997). It is estimated that over 13 million people work as artisanal miners [S6.5 p 68] worldwide (Agency 1999) and many of those are exposed in a manner that leads to health problems.

6 .5. Artisanal.

Hentschel et al. (2002) has described artisanal mining as, “small-scale mining by individuals, groups, families or cooperatives with minimal or no mechanisation, often in the informal [illegal] sector of the market.” Artisanal gold mining is a significant source of mercury release into the environment in the developing world, with at least a quarter of the world's total gold supply coming from such sources, according to the Basil Action Network (BAN 2007). Small-scale gold miners combine mercury with gold-carrying silt to form an amalgam to make gold recovery easier. Much of the retorting to recover gold from the mercury is done in the home using very primitive equipment and polluting the home. A Chemical & Engineering (2007) report stated 220 - 250 metric tonnes of mercury are discharged into the atmosphere from gold mining in China, with Indonesia discharging 100-150 tonnes and a number of other countries discharging variable amounts between 10 -30 tonnes. [Fig 15 page 65].

It is very difficult to pour mercury without splashing or spilling. Falling drops break into small droplets, many of which are too small to be seen with the naked eye. Such small droplets will not agglomerate, so that decontamination of an area where mercury has been spilt is extremely difficult (Goldwater 1972).

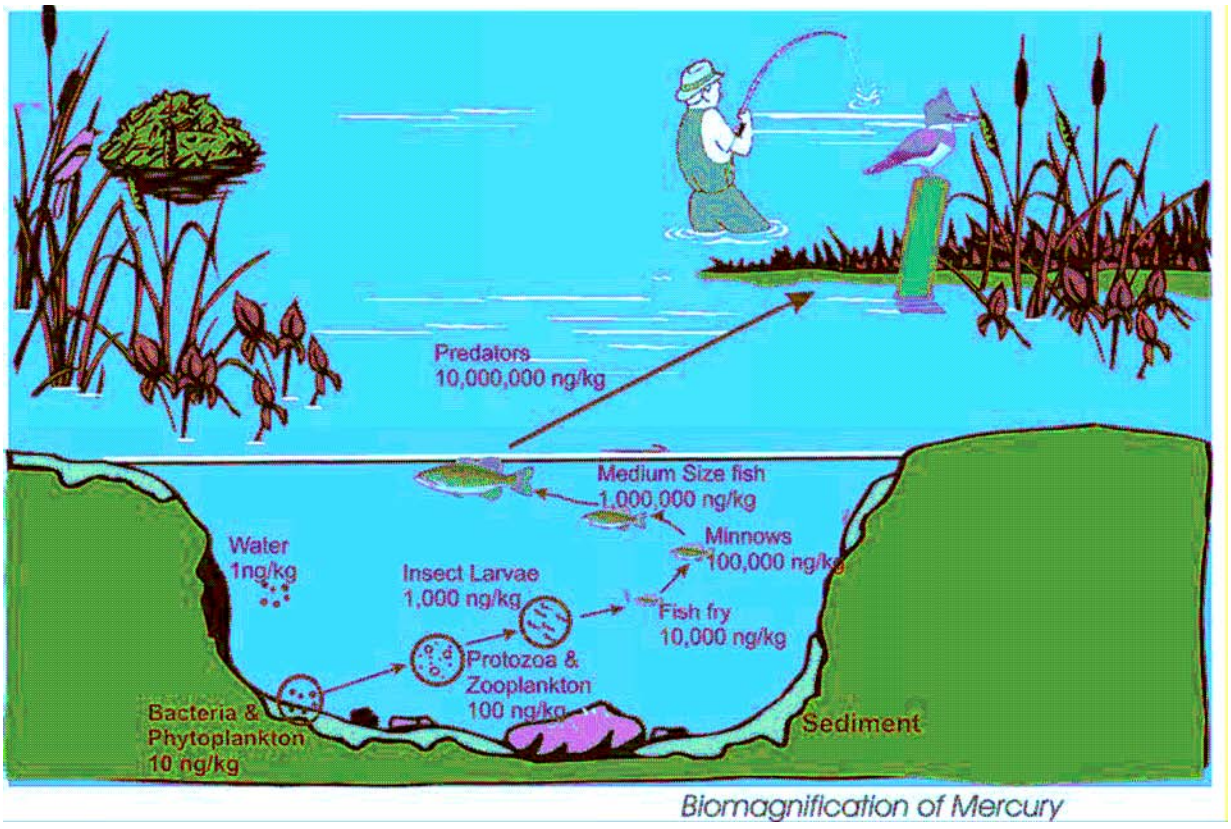
6. 6 Food chain.

A very important factor in the impact of mercury to the environment is its ability to build up in organisms and the food chain. Although all forms of mercury can accumulate to some degree, methylmercury is absorbed and accumulates to a greater extent than other forms. Whereas absorption is a property of the body, bioavailability reflects the nature of the medium or matrix (ATSDR 1999). Inorganic mercury can also be absorbed, but is generally taken up at a slower rate and with lower efficiency than is methylmercury (EPA 1997). Elemental mercury can be converted to methylmercury [CH_3Hg] in aquatic environments by microbial metabolism [biotic processes] such as by certain bacteria and by chemical processes that do not involve living organisms (Lindberg et al. 2001; Ullrich et al. 2001)

A typical pattern of biomagnification is shown in figure 16 on page 70. “Inorganic mercury settles to the bottom sediment where bacteria transform it to methylmercury through the process of biomethylation. It begins with a hypothetical water concentration of 1ng/kg [or 1 part per trillion, 1ppt]. After methylation, the methylmercury [CH_3Hg] is readily absorbed and retained by any organism in the food chain. Each organism eventually bioaccumulates mercury to a concentration of about 10 times greater than in its food. Hence bacteria phytoplankton would have 10 ng/kg [or 10 part per trillion, 10 ppt].

The next, protozoa and zooplankton, would accumulate 100 ng/kg and so on up the food chain and human or other predators (illustrated by a kingfisher) consume fish with 1 million ng/kg [1 ppm] concentration. The entire process is referred to as food chain biomagnification" (ATSDR 1999).

Fig 16. Typical Pattern of Mercury Biomagnification up the food chain.



Source: ATSDR 1999.

6.7. Atmospheric mercury.

The atmosphere is essential to man's wellbeing and the pollution of it is directly related to increased industrialisation and growing urban populations and these are a greater source than natural pollution [e.g. global warming or volcanic eruption].

6.7.1. Mercury cycle.

The environmental mercury cycle is further complicated because certain forms of mercury are volatile (Heiserman 1992). Unlike most metal pollutants whose movement is limited to erosion or leaching pathways, mercury is readily transported in the atmosphere (Carpi 1997) and has an atmospheric half-life of approximately one year (Lindqvist & Rodhe 1985). Elemental mercury is eventually removed from the atmosphere by oxidation to water soluble species and by dry deposition (Carpi 1997).

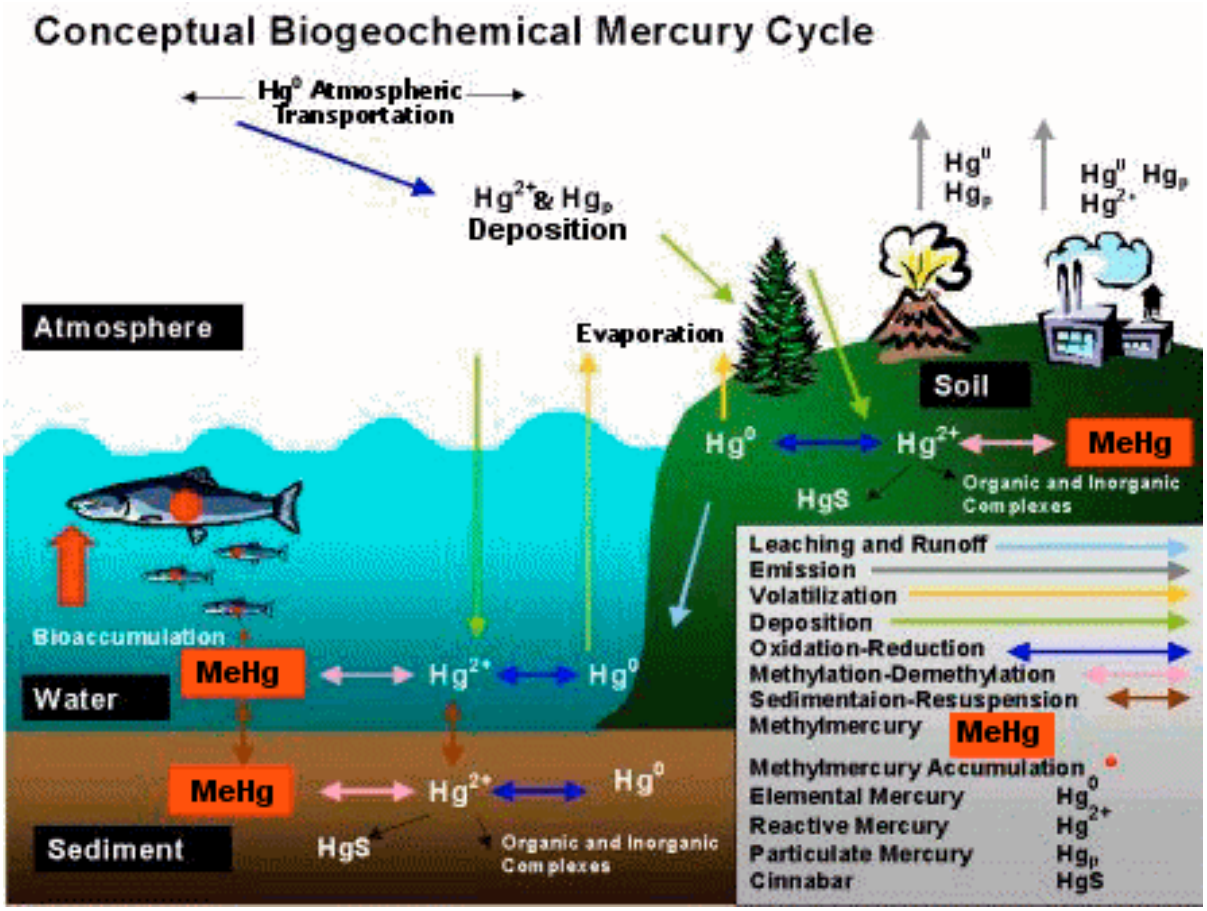
There are two main types of reactions in the mercury cycle that convert mercury through its various forms: oxidation-reduction and methylation-demethylation. In oxidation-reduction reactions, mercury is either oxidized to a higher valence state [e.g. from relatively inert Hg^0 to the more reactive Hg^{2+}]

through the loss of electrons, or mercury is reduced, the reverse of being oxidized, to a lower valence state (Environment Canada 2007).

The oxidation of Hg^0 in the atmosphere is an important mechanism involved in the deposition of mercury on land and water. Elemental mercury Hg^0 can volatilize relatively easily and be emitted to the atmosphere, where it may be transported on wind currents for a year or more and be re-deposited in the environment for further cycling. In contrast, Hg^{2+} has an atmospheric residence time of less than two weeks due to its solubility in water, low volatility and reactive properties. Hence, when Hg^0 is converted to Hg^{2+}, it can be rapidly taken up in rain water, snow, or adsorbed onto small particles, and be subsequently deposited in the environment through "wet" or "dry" deposition (Environment Canada. 2007).

The partition of mercury is affected by environmental parameters such as pH, temperature, redox changes, availability of nutrients and complexing agents (Ullrich et al. 2001). Inorganic mercury has a propensity to bind with mineral particle and detrital organic matter, whereas methylmercury tends to bind with biogenic particles (Meili 1997).

Fig 17. Pctorial depiction of the mercury cycle showing the deposition and volatisation of mercury.



Source: Environment Canada 2007.

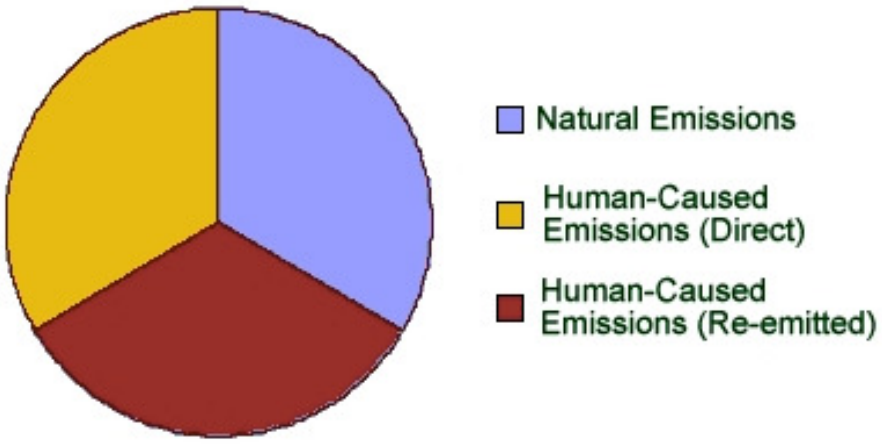
Fig 17 is a simplified mercury cycle that shows the transport and fate of mercury and any contaminated sediments into waterways. It includes overall methylation reactions and bioaccumulation. The actual cycle is much more complex.

6.7.2. Anthropogenic pollution.

Anthropogenic effects or processes are derived from human activities, as opposed to natural effects or processes that occur in the environment without human influences. The atmospheric total of vapour-phase mercury is attributed to anthropogenic and natural sources (Nriagu 1989). Important anthropogenic sources of mercury include the combustion of coal, municipal solid waste and sewage sludge, mining and smelting of metals, and production of chloralkali (EPA 1997). Natural sources of atmospheric mercury include volcanoes, degassing from mercury mineral deposits, emission from surface waters and natural terrestrial emission. In addition, water and soil are affected by atmospheric deposition and thus are integral to the continual global cycling of environmental mercury (WHO 1990).

In fig 18 on page 75 the anthropogenic emissions are roughly divided between re-emitted emissions from previous human activity, natural emissions and direct emissions from current human activity (Seigneur et al. 2004). This graph would indicate that 2/3rds of the emissions are caused by man's activities past and present.

Fig 18. Natural and man made global mercury emissions.



Source: Seigneur et al. 2004. Mason and Sheu 2002 quoted by USEPA mercury emissions: The global context .

6.7.3. Speciation.

Speciation is the term commonly used to represent the distribution of a quantity of mercury among various species of which the main groups are elemental mercury, inorganic and organic forms (Carpi 1997). Speciation plays an important part in the toxicity and exposure of mercury to living

organisms especially its biomagnification (Nriagu 1989). Atmospheric speciation plays an important role in the long-range transport of mercury, [Fig 16 page 70] as well as in deposition mechanisms (Lindqvist & Rodhe 1985)

The atmospheric chemistry of mercury involves several interactions (Pirrone et al. 2001):

- Gas and aqueous phase reactions;
- Partitioning of elemental and oxidised mercury species between the gas and solid phases; the gas and aqueous phases; and also the solid and aqueous phases

The change in speciation of mercury from inorganic to methylated forms is the first step in the aquatic bioaccumulation process (Pirrone et al. 2001). This can occur non-enzymically or through microbial action. (Carpi,1997; Pirrone et al. 2001a). Organic matter affects the level of methyl mercury through influencing the microbial activity and controlling the partition of Hg between solid and dissolved phase by serving as complexing agents for Hg^{2+} and methylmercury (Lambertsson & Nilsson 2006).

Chapter 7. Amalgamation.

7.1. History.

Amalgamation is one of the oldest methods of extracting gold from its ores. According to Malm (1998) it has been used for more than 4500 years. Because mercury alloys easily with many metals, such as gold, silver, and tin it is a very desirable and cheap means of recovering fine gold. An article in Chemical & Engineering News (2007) stated "Amalgamation of gold ores as described by Agricola in *De Re Metallica*, which was published in 1556, is essentially the same as modern practice. The only changes are in the machinery employed and the source of power to grind, mix, and separate. However, although the chemical and physical processes are more clearly understood by more recent authors, the actual hands on instructions are remarkably similar and *De Re Metallica* can still be used as a reference."

7.2. Theory of amalgamation.

Although the physical and/or chemical characteristics that make amalgamation work are not clearly understood, it is known that if clean mercury is brought into contact with clean gold, they combine or amalgamate. This gives an alloy of gold and mercury called amalgam. The gold can be removed from the amalgam by dissolving mercury in nitric acid or by driving it off as vapour using heat and leaving the gold behind. For amalgamation to take place the gold and mercury must be brought into contact with each other. To achieve this, gold particles need to be separated from the fine mix of sand and silt and the gold and mercury kept clean and bright. Once the amalgam has coalesced it can be treated to extract the gold (Baird 1987).

Amalgamation works best on relatively coarse gold that is clean. Mercury will not penetrate into minute crevasses or pores so the ore must be ground fine enough to expose the gold at the surface. Very fine gold is often hard to save using mercury, and other methods are usually required, [cyanide process]. The presence of sulphides of arsenic, antimony or bismuth [impurities in gold] will cause the mercury to become “dirty” and this makes the recovery of gold by amalgamation difficult.

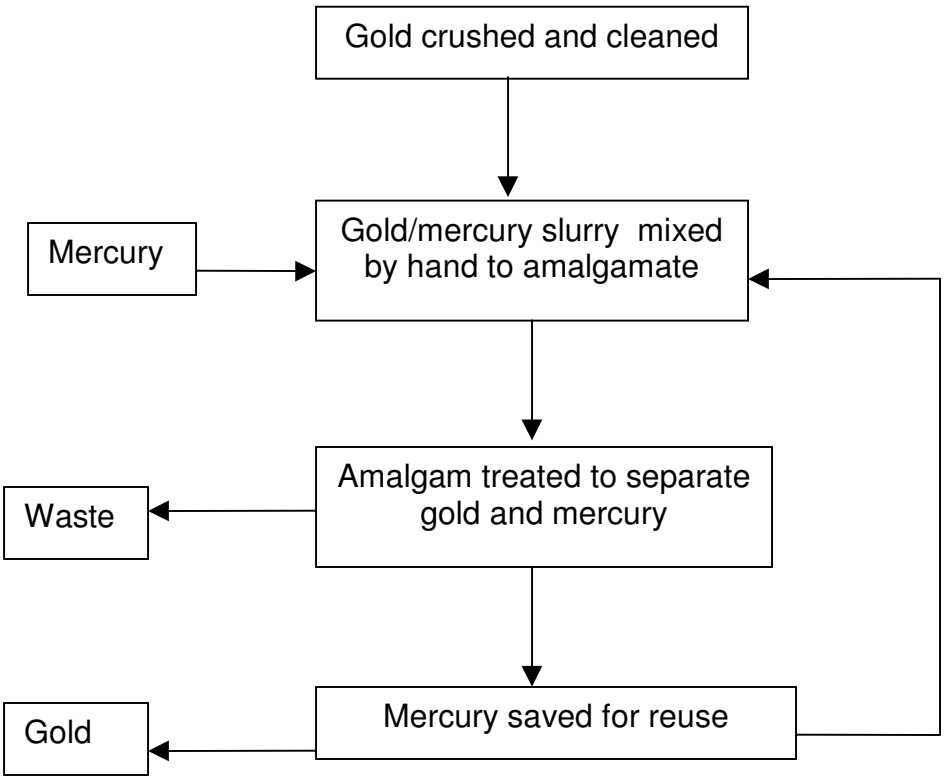
If the mercury will not wet, or take up the gold, or coalesce into larger globules it is described as being “sick“ - most likely caused by impurities in, or on, the surface of the mercury (Baird 1987). Baird calls this “flouring” which is the division of the mercury into extremely small globules that gives it a white flour-like appearance. This makes the mercury more susceptible to sickening while it is in the finely divided state and it will not coalesce. Any gold that was

combined with the mercury before it sickened is likely to be lost. This' "dirty" mercury can be purified by distillation or a dilute nitric acid wash which will remove base metals, or it can be filtered through chamois skin to remove impurities (Beard 1987).

The stages of the manual amalgamation process are shown in the schematic diagram in Fig 19a. This diagram has been drawn up by the author based on the information contained in this document

Fig 19a. Diagram of the gold saving process after gold is crushed and mercury added to form amalgam.

Source: Author diagram.

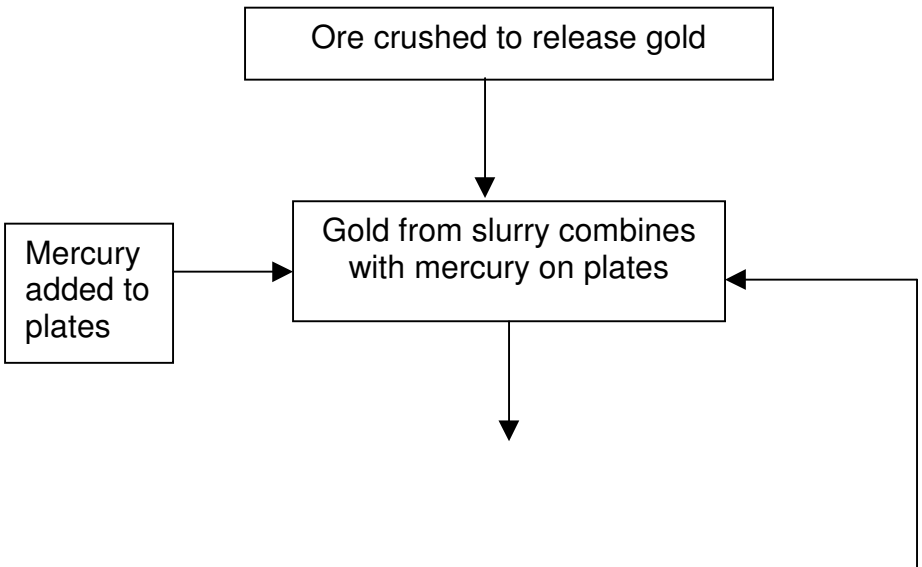


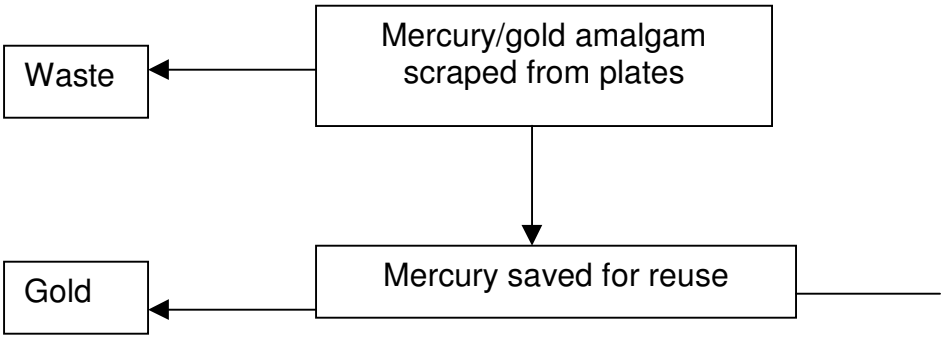
In the larger mining companies the amalgamation process, where used, is more mechanised and each of the above steps is incorporated using a continuous process. A method used on the early New Zealand goldfields involved the stamp mill where the ore was crushed and the gold slurry was

directed over amalgamation plates. The stamp mill was replaced in the 1930s by the ball mill where mercury was fed into the tumbler of the mill with the ore and then passed over prepared plates.

The plates, which are pure annealed copper are scoured with sand and lye to remove any coating or oxidation, then rinsed with clean water and washed with a 2% to 3% solution of cyanide. A mixture of sal ammoniac and fine sand in solution with mercury is scrubbed onto the plate and as much mercury as the plate can hold is added. After coating, the plate is washed with clean water and rinsed with the cyanide solution .

Fig 19b. Use of mercury plates to continuously save gold. [Author diagram].





The gold slurry mix flows over the plates where the gold sticks to the mercury and gradually dissolves to form amalgam. When the plates are loaded with amalgam, mercury is sprinkled on the surface to soften it and the whole surface scraped with a hard wood or rubber scraper to remove the amalgam. The whole process of adding mercury to the plates is done again and the plate returned to service.

After the amalgam is collected the larger globules are separated from the slurry. Gravity separation is usually employed. Sluices, jigs, tables, wheels, pans or any other gravity devices are used. The excess mercury is removed by squeezing it though a damp chamois or canvas leaving a hard lump of amalgam ready for retorting (Beard 1987).

Plates are no longer used but the manual process is still used by small gold miners to recover gold from placer / alluvial deposits. This method requires no advanced equipment or procedures, just an amalgamation table, some buckets, and the mercury as shown in Fig 19a, p 79. It is a wasteful procedure, and not only is fine gold lost, but more importantly, so is mercury

to the environment. UNEP (2005) estimated 100 tons of metallic mercury is dispersed to the environment in the Brazil region every year by small miners. No quantification of the gold lost has been done. Apart from the environmental damage from the lost mercury there is a financial cost from the loss of fine gold that is carried off to waste with the mercury.

7.3. New Zealand mines & amalgamation.

Amalgamation plates were used in New Zealand historically into the early 1900s and then they were phased out in favour of the cyanide process. This process was too expensive and labour intensive for the small miners who continued to use mercury with the manual process. Currently in New Zealand [2007] mercury appears to still be the chemical of choice for small miners to save gold.

During the period of this study all participants were using the manual mercury amalgamation process as their means of gold recovery. [S3.5. p 28]

Chapter 8. Research Objectives.

8.1. General.

A literature search carried out during the study, and since it was revisited, did not find any research into the New Zealand gold mining industry. The author decided to carry out a study of the gold mining industry on the West Coast of New Zealand's South Island with the intent of investigating the use of metallic mercury. This was the first and, to-date, only study on the subject within a New Zealand context. We know that mercury affects the environment and the food chain as research has been done on this (Carpi 1987; WHO 1990; EPA 1997; Ulrich et al. 2001.) The toxicity of metallic mercury and its effects on humans has also been well researched (NAS 1978; Roels 1982; Clarkson 1989; WHO 1991).

8.2. Specific objectives of this study were to:

- Investigate the use of mercury in the West Coast gold mining industry.
- Identify any problems associated with its use.
- Make recommendations based on the study findings.
- Identify areas for future research.

Accessibility to mining sites and their distances from the office created difficulties in carrying out this research. A lack of resources as well as a reluctance of some miners to be involved in the research [for various reasons] added to the problems that had to be overcome before a meaningful study was started. Months were spent in overcoming miner resistance/ suspicion and obtaining the minimum of resources.

Chapter 9. Health and Safety.

9.1. General

Modern gold mining is an industry that has risk associated with it. Risk that is known and planned for is the operation of heavy machinery, heavy lifting and slips or falls. Chemicals are an essential part of the industry but often risk is ignored due to a lack of knowledge, or the need to get the job done. Mercury is one of the chemicals used and Larcerda (1997) states that over 20,000 people were afflicted by mercury poisoning over a 40 year period and most of this was industrially based. History shows that mercury, whilst being of benefit in some industry, creates many problems (WHO 1991; WHO/IPCS 2002).

9.2. Occupational Safety.

9.2.1 Legislation.

At the time the study was undertaken [1984-88] the relevant New Zealand legislation covering the gold mining industry were, The Mining Act 1971, The Factories and Commercial Premises Act 1981 and the Quarries and Tunnels Act of 1982 and Regulations made under those Acts. A Workplace Standard based on the American Conference of Government Industrial Hygienists (ACGIH 1976) that set a TLV [see glossary] for chemicals in occupational use, was adopted by the New Zealand Government. These Standards set a level for mercury in air of 0.05 mg/m^3 in the workplace and were used by the Health Department and Labour Department for air measurement compliance. There

have been major changes to Health and Safety legislation since this study was carried out. [S9.2.4].

9.2.2. Administration.

As stated above, during the period of the survey [1984-88] the main Health and Safety legislation in force were:

- The Mining Act 1971, The Quarries and Tunnels Act 1982, and Regulations under those Acts, administered by the Mining Inspectorate of the New Zealand Mines Department, a Government department. The mining industry on the West Coast was the largest in New Zealand and it covered both coal and gold mining. There were [3] three mining inspectors based in Greymouth to service the West Coast region.
- The Factories and Commercial Premises Act 1981 and Regulations, administered by the Labour Department, a Government department with an office in Greymouth staffed by [3] three Factory Inspectors.
- The Health Act 1956 and Regulations, administered by the Department of Health, a Government department, with an office in Greymouth staffed by one [1] Inspector of Health.

These [3] three Government departments were responsible for the administration of all occupational health legislation anywhere in New Zealand.

At the time of the survey the Department of Health had specific occupational health responsibilities in regards to worker's health under Regulations made

pursuant to the Health Act 1956, but mining was not one of them. The author was the resident Senior Inspector of Health in the Greymouth office at the time of the survey. Due to the fact that the specific Statutes were administered only by the department responsible for that legislation during the period, the oversight of gold miner's health and safety was split between the Mines Department and the Labour Department. The Mines Department had the main responsibility for mine safety with the power to prosecute. Although the Health Department had an involvement in occupational health generally, it only had a limited role in the mining industry as an advisor to the other Government departments.

Some companies had mining, gold processing and administration on the one site and other companies had their gold processing facilities and administration at a site away from the mine. The Mines Department Inspectorate was responsible for any site that was part of the mining licence with the Labour Department Inspectorate responsible for any work site that was not part of the mining licence. The Health Department Inspectorate collaborated with these two Government departments as consultants, carrying out measurements and providing advice on results, but did not enforce legislation in mining. This complicated matters in that it increased the number of officials involved and added to the problem of administering the legislation to ensure worker's health and safety was not compromised.

9.2.3. Compliance.

The legislation at the time of the survey was adequate to cover physical work type incidents but not to cover the use of mercury [or other chemicals] in the gold mining industry. There had been a long period between the goldfield activity of the late 19th Century and the new activity of the 1980s [approx 60 years]. With an industry in decline there was no need for new legislation that specifically covered mercury use in gold mining, so when the new gold rush occurred the "Inspectorate" was not legislatively equipped, or trained, to deal with it. The Mining Act 1971 and The Quarries and Tunnels Act 1982 were promulgated to cover coal mining and had little relevance to gold mining. Because of this time lag between the "gold rushes", The Mines and Labour inspectorate, although qualified to carry out their respective roles as it related to the legislation they policed, had no experience or knowledge of mercury as used in the gold mining industry.

Prior to this study being done [1984-88], no investigation of mercury use in the New Zealand gold mining industry had been undertaken. The Mining Inspectorate had more interest in coal mining which was a major industry at the time and where their expertise and knowledge was based. The Labour Department Inspectorate's expertise was in physical safety, mainly in factories and forestry, and they had no experience in air monitoring or personal sampling technique. The Mines Inspectorate had carried out some routine urine sampling of mining personnel but this information was filed without any follow up or analysis of the results. No workplace measurements were carried

out by either Inspectorate. Consequently the level of compliance with Standards was not known prior to this study. Very little research was available on the gold mining industry at all. As the study has shown, the level of compliance was not good and it was more by good luck than good management that the level of non-compliance found was not greater.

9.2.4. Current legislation.

There has been a major change in legislation relating to Health delivery in New Zealand since this survey and this has had implications for occupational safety. Beginning in 1983, New Zealand's health system was subjected to two decades of reform. Up until the 1980s, Hospital Boards had a strictly hospital focus and were publicly elected [the Department of Health ran non-hospital public health and some mental health services]. The Government of the day decided to integrate hospital board curative services with the preventative focus of district health offices. Fourteen [14] Area Health Boards [AHBs] were created to provide funding to each region on a population basis. This reform continued through the 1980s and was characterised by an explosion of acronyms. Area Health Boards combined hospital and public health services and their boards were partly publicly elected and partly appointed by the Government (MOH website visited 10.09.08).

On 1 July 1993 a massive reform took place and the 14 Area Health Boards became 23 Crown Health Enterprises [CHEs]. CHEs were expected to compete via the market and meet service for money targets. Four Regional

Health Authorities [RHAs] were set up to provide the funding to CHEs; they in turn came under a Public Health Commission [PHC], under the renamed Ministry of Health [MOH, as opposed to the old DOH]. CHEs were renamed Hospital and Health Services [HHSs] in 1996, with greater emphasis on service provision. However, the idea that hospitals should compete remained a major part of Government thinking (MOH website visited 10.09.08).

In 1999 the final round of reform was carried out replacing HHSs with the current District Health Boards [DHBs]. They are responsible for providing [or funding the provision of] Government funded health care services for the population of a specific geographical area. There are 21 DHBs in New Zealand.

The statutory objectives of DHBs include improving, promoting and protecting the health of communities, promoting the integration of health services, especially primary and secondary care services, and promoting effective care or support of those in need of personal health services or disability support (H&D Act 2000). Unfortunately the DHBs still have a curative approach to health care that does not sit well with their public health role (MOH website visited 10.09.08).

With the Department of Health [formerly containing field staff] undergoing reforms during the same period and becoming a Ministry [comprised of advisors], there have been changes to field staff. Inspectors of Health have now become Health Protection Officers [HPOs] with much reduced powers

and roles. Support staff for the field officers in head office have been made redundant and replaced by the afore-mentioned advisors. Legislation administered by HPOs has gradually been revoked, or incorporated in other legislation administered by other departments or local authorities. The splitting off of Health Protection activities to other bodies has resulted in fragmentation of health delivery and health protection.

Coinciding with this major change to health delivery other changes took place. In 1990 the New Zealand Government decided that the current situation, whereby occupational health and safety delivery was fragmented over a number of Government departments, was not delivering a good service. It decided that the only way to improve occupational health and safety delivery was to put responsibility under one department. It chose the Department of Labour [previously called Labour Department] as the controlling authority. An Occupational Safety & Health [OSH] branch was set up under the umbrella of the Department of Labour and The Health and Safety in Employment Act [HSE] was passed in 1992. This Act consolidated current health and safety requirements by revoking all the old legislation [The Mining Act 1971, The Quarries and Tunnels Act 1982, and Regulations under those Acts; The Factories and Commercial Premises Act 1981 and Regulations; and various occupational Regulations under the Health Act 1956]. Specific rules were promulgated for mining in the HSE [Mining Administration] Regulations 1996.

The aim of the new Health and Safety in Employment Act 1992 is:

> … *to promote the health and safety of everyone at work and of other people in or around places of work. To achieve this, it requires people who are responsible for work and those who do the work to take steps to ensure their own health and safety and that of others. The Act also recognises that employees have a valuable contribution in making workplaces safe.*

The Department of Labour revoked the old 1976 Standards [S9.2.1. p 84] and replaced them with The Workplace Exposure Standards which became effective from 1994 [updated in 2002]. Mercury is included among the substances that have been assigned a TLV in these Standards. However, compliance with the Standards does not guarantee protection from ill-health outcomes for all workers, due to the wide range of individual tolerance. The publication has detailed information on how the Standards are set and how they should be used. They are a guide only under the Health and Safety in Employment Act 1992, but under the Hazardous Substances and New Organisms Act 1996 [HSNO] and subsequent Regulations, they are enforceable as part of a hazardous substance control. With the promulgation of the Health and Safety in Employment Act 1992, Health Protection Officers ceased to have any involvement in occupational health.

The effect of these changes to occupational health delivery and legislation on present day gold mine worker's health is further covered under S14.

Chapter 10. Methodology.

10.1 General.

The gold mining workforce consisted entirely of males and with an age group range of 18 years to >60 years, and a mean of 26 years. The gold mining experience of employees involved in the study ranged from a few months to many years with a mean of 20 months. Work periods were all very similar in hours worked [40 hours per week average]. However, some worked shifts that alternated between night and day time on a week about and others worked just day time. All participants in this study were involved with mercury for at least 6 months at time of selection.

This study examined the use of mercury in the gold mining industry through work place air measurement, observation of processes and procedures, personal monitoring, and discussion with employees. It looked at the exposure of employees to mercury through their work processes. Exposure in this study refers to any direct or indirect contact with mercury. As the study required the collection of different data over the period of interest, and employee and company time was involved, it was critical that the mining companies were brought on board and that there was minimal interference with their work. To obtain and keep the goodwill of the personnel involved, especially management, worker involvement was kept to a level consistent with obtaining meaningful results.

To achieve this, visits were kept to a minimum and some personal and company data was obtained from historical files [1984 – 1986].

Although the period of interest is 1984–1988, the monitoring was carried out between January 1986–June 1988. Personal sampling data relating back to 1984 was made anonymous before being received and was collected from historical files. To achieve the objectives of the study the following methods were used:

- Biological monitoring of employee urine samples [Hg-U].
- A subjective questionnaire designed by the author.
- Work place monitoring of mercury vapour in air levels [Hg–air].
- Personal mercury vapour exposure sampling.
- Observation of worker's methods and processes used.
- Observation and examination of protective equipment provided to workers.
- Observation of the work rooms and facilities.
- Discussions with workers and management.
- A literature search involving publications and web search.

Laboratory analysis of biological samples was carried out at the Department of Scientific & Industrial Research [DSIR], now called the Institute of Environmental Science & Research [ESR] a Crown research institute.

10.2. Cohort.

The participants [n=16] chosen to take part in this study were all men as no women were employed in this industry. They ranged in age from 20 to >60 years of age and had been involved in the gold mining industry between 1 and 40 years. All had been involved with mercury for at least 6 months before the study. They were a representative sample of those involved in the industry despite the fact that not all those that were considered ideal were willing to take part. Due to the number of employees in the small companies the choice was limited in that only one person handled the mercury.

Altogether 16 participants were chosen, 8 who handled mercury but did no retorting and 8 who did retorting. All were from different companies giving a total of 16 companies involved in this part of the study. Each participant was given a random identification number that enabled all data relevant to that person to be kept together and ensured that identification of the person remained confidential. Participants were spoken to individually and informed about the study, what it wanted to achieve, and how it would impact on them. They were given the opportunity to ask questions and raise any issues of concern and were kept up to date with progress of the study. They were also given the right to see all information and data collected regarding them.

10.3. Control.

The control group was made up of up of employees [n =12] who worked within the gold mining industry and were of a similar makeup to the cohort under study, but not involved with mercury. This was made up of 6 personnel from separate companies and 2 each from 3 companies. Because of the possibility of cross contamination by mercury in the work place, all these participants were chosen from field workers. The controls were given a random identification number and supplied a 24 hour urine sample each year [3 samples per person in total] and they were asked to fill out the questionnaire. The results from this group were used as a comparison with the mercury handlers/ retorters. They were also given the right to see all information and personal data collected about them.

10.4. Observation.

An important part of the study, this was undertaken at the first visit to a premise and involved a walk through inspection of work places to look at facilities, processes / practices and protective equipment. A plan of action was drawn up for each work place. At the time of the study there were no mandatory standards for building structures or retort ventilation in regard to mercury use. The use of protective equipment was based on general safety rules rather than any specific to mercury. Visits were also made to observe, rather than measure to pick up on any crucial changes to process that might impinge on the original plan for the site.10.5.

10.5. Biological sampling.

Biological monitoring is the measurement of a chemical agent in the blood, urine, or other body tissue of exposed individuals to determine how much of the chemical has been absorbed into the body. It serves as an additional evaluation of environmental exposures and is important because air measurements can't assess skin exposure or the effects of work practice. It is a better estimate of risk than air monitoring since it measures the actual amount absorbed into the body (WHO 1990).

Blood and urine levels are used as markers to determine exposure to mercury (Piotrowski 1975; ATSDR 1999). Urine sampling was used instead of blood sampling because the drawing of blood is an invasive technique. Mercury levels in the blood decrease by ½ every 3 days if source is removed therefore blood is more useful as an indication of recent exposure than for long term or continuing exposure (Roels 1982; OSHA 2007). This study covered long term usage, and 24 hour urine samples give an average past history of metallic mercury exposure (WHO 1976).

Exposure to heavy metals through daily living results in the body of an average person exposed to natural environmental sources reaching a steady state, through absorption and excretion (WHO 1976). Therefore, we would expect to find a small amount of mercury in people's urine. In the workplace, sampling of urine for mercury will give a meaningful picture of exposure for research (WHO 1976). It is easy to collect and non -intrusive.

10.6. Urinalysis [Hg-U].

The objective of the sampling was discussed with each participant and none objected to supplying 24 hour samples. Spot sampling of urine for mercury was considered to be inferior to 24 hour sampling which is the recognised method for meaningful results (Roels 1987).

Past urinalysis had been carried out on workers handling mercury as part of the Ministry of Mine's work place checks and, inclusive of these, a total of 153 samples were analysed over the period of interest 1984–1988. These included samples already done for Long-term employees as part of the on-going check by the Inspectorate in 1984-85 and the participants in the study. Samples were anonymised to prevent identification of persons. Samples [40] analysed before the start of this study [1984–85] were historical and obtained from Mines Department records with the permission of employees, and those from January 1986 [113] were collected as part of the study. The historical samples were all 24 hour volume, as were those taken throughout the study.

As mentioned earlier the rationale behind 24 hour urine sampling was explained and the participants were given instructions regarding the collection of urine over the 24 hour period and how to prevent contamination of the sample from their clothes, skin or workplace. Sample containers [containing a preservative] were supplied by the laboratory for collection of urine. All samples were collected by the author and dispatched to the laboratory.

10.7. Literature search.

Between 1986–1988 a literature search reviewed reports, documents and research papers on mercury to obtain information on the chemical and its toxicity to humans and the environment. With the study revisited for this thesis in 2007 a further literature search was undertaken and the World Wide Web [www] was also used. From the initial literature search in 1986-88 it was thought, by the author, that the amalgamation process was likely to be a lesser problem of mercury contamination than that of retorting. Based on this perceived risk difference the mercury handlers were split into [2] two groups, non–retort operators and retort operators. This identification has been used throughout this study and enabled the risks associated with each operation to be separately quantified.

10.8. Questionnaire.

A simple questionnaire that was drawn up by the author and not peer reviewed [appendix 1] was used in conjunction with urine monitoring. Symptoms recognised as being part of the suite of symptoms associated with mercury poisoning were included. The questionnaire was designed to be subjective and the participants were asked to indicate if they suffered from any of the listed symptoms at the time of giving a sample of urine. No clinical testing was carried out to prove or disprove the questionnaire responses.

10.9. Employee discussion.

Discussions were held with employees of the sites [n=25] visited to obtain an indication of the experience, knowledge, training and work procedures that were employed when handling mercury. Any concerns that they had regarding mercury were also canvassed at this time.

10.10. Environmental monitoring.

Environmental monitoring involved gathering data from the work place environment of the mercury handling employees by:

1. Measurement of mercury in air levels [Hg–air] using a portable mercury analyser.
2. Ventilation readings on extraction systems using velocity meters and smoke tubes.
3. Dräger hand pump and mercury tubes for mercury in air levels [Hg-air].
4. Limited use of personal mercury dose badges.

In this study Dräger tubes were used to measure workroom mercury in air [Hg–air] levels when the detection limit of the mercury meter was reached.

Smoke tubes were used to indicate air current direction and the efficiency of vapour capture by ventilation hoods and fans. Anemometers were used to measure air flow in work places where mechanical ventilation was in use and to check their efficiency.

10.11. Mercury meter.

The Gold Film Mercury Vapor Analyzer [mercury sniffer], model 411 [appendix 2] was designed for the easy and accurate analysis of mercury vapour in the workplace environment and for the location of mercury spills. The minimum detection level was 0.001 mg/m^3 Hg @ 0.75 L/min of air and the top detection limit was 1mg/m^3. It was powered by a rechargeable battery pack that gave 6 hours of operation. The analyzer had a 10 second sample mode that provided an integrated, direct reading of mercury vapour concentrations in mg/m^3 and a 1 second survey mode that enabled qualitative determination of mercury levels. A microprocessor automatically re-zeroed the meter at the start of each sample cycle and prevented drift between samples. Sample results were displayed on the screen. An internal charcoal filter was provided for calibrating purposes.

The analyzer contained a thin gold film that in the presence of mercury vapour underwent an increase in electrical resistance proportional to the mass of mercury in the sample. This gold film was selective in its adsorption of elemental mercury and this eliminated interferences such as water vapour,

particulates, cigarette smoke, magnetic fields and organic solvents. As mercury was adsorbed onto the sensor, the percentage of saturation was indicated by pressing the sensor status button. Limitations of this machine were that it could be overloaded due to high mercury vapour levels; and, vapour levels had to be read at the time of measurement as there was no memory or recording mechanism.

Approximately forty 40 X 10 second samples containing 0.1 mg/m^3 of mercury could be taken before the sensor was saturated. Cleaning of the sensor [desorbing] required a 15 minute heat cycle to be manually activated to remove the saturation.

The analyzer was used as a handheld mercury meter in walk about measurements [Hg–air]. An advantage of this analyzer was that it could be positioned anywhere and give a direct reading, being especially useful for grab sampling. The meter was used for measuring worker's breathing zone levels, clothing contamination, work surface contamination and room air measurement.

10.12. Personal dose badges.

Fig 20. Sampler badge.

Diffusive monitors [Fig.20] have been used for workplace air monitoring for many years, and have been found to be valid and cost-effective alternatives to conventional pumped or 'active' samplers (Brown 1993). A diffusive sampler is a device which is capable of taking samples of gas or vapour pollutants from the atmosphere at a rate controlled by a physical process, such as diffusion through a static air layer or permeation through a membrane, but which does not involve the active movement of the air through the sampler (Berlin et al. 1989). The sampling rate of the dosimeter badge at 20℃ was 0.020 L/min when used in face velocities normally seen in industrial environments with a detection limit of 0.002 mg/m^3. The sampling rate can vary with ambient temperature changes that affect the diffusion rate. This is a small effect but may be significant if sampling at very high/ low temperatures. Precision and accuracy was 0.061 to 0.20 mg/m^3 with an overall error rate of ± 8.6% and a bias of +0.008 (US Dept of Labor 1989).

These badges were used to obtain a time related dose for individual workers. They were a lightweight, reusable lapel badge containing a sorbent capsule. The sorbent material [Hydrar] collected mercury in air through controlled diffusion by chemical interaction due to an irreversible affinity for mercury. The mercury was collected on a solid Hydrar sorbent capsule in a plastic housing.

The Hydrar was analysed by cold vapour and the capsule was discarded and the plastic housing was decontaminated for reuse. No pumps were required and this made for ease of use. Sampling intervals could be as little as 15 minutes or as long as a week depending on expected mercury concentrations. In this survey they were used in 2 x 4 hour periods. They had the advantage of sample stability due to the irreversible affinity of mercury with the hydrar and were not affected by moisture.

Measurement function was achieved by chemically desorbing the mercury into a solution and analysing this by Flameless Atomic Absorption. The mass of mercury on the Hydrar is directly proportional to the concentration in the original atmosphere over the sampling period and a simple calculation allowed a time weighted average [TWA] to be determined. These badges were in short supply and were used in selected cases, usually where previous Hg–U results did not appear to have a direct relationship with recorded mercury in air levels [Hg–air].

When in use they were attached to the collar, or as close as possible to the breathing zone of the wearer. They were left in place for the nominated time period and then removed and dispatched to the laboratory for analysis.

10.13. Dräger Tube

Fig.21. Dräger bellows pump with tube in place.

The Dräger tube system [Fig. 21] is an established method for measuring and detecting contaminants in the soil, water and air. The Dräger tube method of measurement can be used for gas/ vapour analysis. Dräger tubes are glass vials filled with a chemical reagent that reacts to a specific chemical or family of chemicals. A calibrated 100 ml sample of air is drawn through the tube with the handheld Dräger bellows pump. If the chemical [mercury] is present the reagent in the tube changes colour and the length of the colour change typically indicates the measured concentration.

The measuring range for mercury tubes was 0.1 mg/L to 2 mg/L. Sampling the air required that both ends of the tube were broken off and the tube positioned into a Dräger pump; the air was drawn through the tube by the required number of pump strokes [marked on tube]. The mercury in the air sample drawn through the tube reacted with a chemical in the tube to give a colour change.

The actual concentration of mercury in the sample was calculated by checking the length of the colour change in the tube and, using the formula mg/m^3 Hg = 2/n where n equals the number of strokes used, arriving at a measurement. They were easy to use and inexpensive.

10.14. Air flow.

Exposure assessment is a critical part of epidemiological studies and air sampling is important for occupational assessment. Air movement within a workroom can have a big impact on worker's health in that it can transport vapours around a room. Knowledge of air currents provide information as to where vapours flow within a room. It is important to know where mercury vapours will be transported by the air currents within the room to enable systems to be designed to remove them. As part of this strategy for vapour control it is essential that fresh air is used to make up the air that is removed when using a local exhaust system. To collect this information anemometers and smoke tubes were used.

10.14.1. Anemometers.

These instruments measure air speed and need to be calibrated against recognised standards. A rotating vane anemometer records the linear movement of air in metres or feet over a period of time. The rotating vane inside the instrument forms part of an electronic transducer, which offers little

resistance to flow and provides good average readings. The design allows for the measured velocity to be displayed instantaneously on the screen.

To have a “safe” work room it is necessary to have the right number of air changes, and more importantly, to ensure that the airflow into the room is sufficient. Although air changes per hour give an indication of air supply, they relate to the volume of the room, which is an incorrect unit of measurement. Measuring air velocity is a more accurate way of determining the cleanliness of the room: the higher the velocity, the cleaner the room. However, for personal comfort it is essential that velocity of air is not such that it creates a draft and uncomfortable working conditions. That in themselves can cause other occupational problems. The measurement range of the instrument was 1 to 30 m/s.

10.14.2. Smoke tubes.

Smoke tubes [fig 22 p 107] produce a harmless cloud of white smoke that floats freely and easily, because it has the same density as ambient air. Using a smoke tube for airflow indication was a simple, cheap and effective method for tracing and determining the source, direction, and dispersion of air currents.

Fig.22. Smoke tube kit.

The highly visible white smoke provides an immediate and obvious direction to the pattern of air currents and the slightest air movement becomes visible. Use of the tubes required breaking off the tube ends, inserting the tube into the hand bellow and squeezing the bulb to force out the smoke. They were ideal for checking ventilation or air conditioning systems, or detecting leaks in industrial equipment. Detection of contaminants in work areas and finding the best locations for measurement of contaminant concentration requires knowledge of air movements.

Smoke tubes were used extensively during the study. They also had the advantage of being used as an educational accessory, due to the high visibility of the smoke, to show employers and employees what was happening with vapours in particular workrooms.

Chapter 11. Results.

11.1. General

This section brings together the results of all measurement and historical data collected, and observations made, over the period of the study 1984-1988. All figures and tables of measurements are positioned within this chapter. Further reference is made to the data in the discussion section [Chapter 12, p 160].

11.2. Personal protective equipment. [PPE].

Personal protective equipment, or PPE, is designed to protect employees from serious workplace injuries or illnesses resulting from contact with chemical, radiological, physical, electrical, mechanical, or other workplace hazards. Besides face shields, safety glasses, hard hats, and safety shoes, PPE includes a variety of devices and garments such as goggles, overalls, gloves, vests, earplugs, and respirators. Using PPE is often essential, but should be the last line of defence after engineering controls and good work practices to reduce worker exposure. PPE should never be used as a replacement for taking all practical steps to reduce adverse effects on worker's health by other means.

Workers should use appropriate personal protective clothing and equipment that must be carefully selected, used, and maintained to be effective in preventing skin contact or inhalation of mercury vapour (US DoL 1985). The equipment recommended by the New Zealand Department of Labour in the 1980s for chemicals in general were, gloves, overalls and masks. The quality of these basic protective items, where provided, varied considerably. Very little training was given on use and maintenance and there was no follow up by management to ensure that staff used any protective equipment. The current exposure standard [TLV] for elemental mercury in New Zealand is 0.05 mg/m^3 and is a time weighted average [TWA] concentration for an eight hour day, five day week (DOL 1975).

The current situation requires that for adequate worker protection PPE must:

- Be appropriate for the task.
- Prevent or sufficiently reduce the risk.
- Fit the wearer and be comfortable.

If PPE is supplied the employees must be required by management to use it,

11.2.1. Masks.

When engineering controls are not feasible, workers must use appropriate respirators to protect against adverse health effects caused by breathing air contaminated with harmful mercury vapours. Respirators generally cover the

nose and mouth or the entire face or head to help prevent contamination and illness. A proper fit is essential for respirators to be effective and all employees required to wear respirators need to undergo a fitting session to ensure that the respirator fits their face profile. This will ensure that the mask will not leak and let contaminated air in. This is especially important where the wearer has a beard as beards prevent the mask seal from being effective.

At the time of this study PPE rules did not exist. Disposable masks were used in situations where they were ineffective, giving a false sense of security to the wearer. Some masks were only suitable for dust and not vapours. Where cartridge filter masks were used some had the wrong cartridge type fitted. No records were kept of when a cartridge was changed or how much use a mask had, and in many cases no instruction was given to the employee on use and maintenance of masks. Masks were seldom protected from contamination when not in use, often left in the retort room and no cleaning schedules existed to ensure masks were washed and cleaned between uses. Regrettably, procurement of masks and filters was carried out with limited knowledge of the types required and how to maintain their effectiveness.

11.2.2. Clothing.

Protective clothing is essential in this industry but was not always supplied. Gloves and eye protection were not provided in many work places. Most employees wore overalls, usually their own, but few workplaces had a policy for daily changing or washing of work clothes. Employees wore the same

overalls for days and, if washed, they were taken home to be done. Overalls are part of protective clothing and if contaminated the wearer is constantly exposed to that contamination until they are changed or washed. It became obvious early in the study that work clothing was being contaminated by mercury.

When the author became aware of the possibility that contaminated clothing was a source of personal contamination to the wearer, a series of tests were designed to measure clothing contamination levels. The overall wearers were removed to another room where no mercury was present, or into the outside air, and the mercury meter was used to “sniff” the clothing to see if any vapour was given off. Overalls were monitored first thing in the morning before workers put them on to see if any residue remained.

An example of how this clothing measurement was carried out: measuring the Hg–air level in the retort room at the start of a shift gave a reading of 0.035 mg.Hg/m^3air prior to starting the retort. The room temperature was 18 ^{0}C [64^{0}F] and within ½ an hour of firing the retort at 1030 hours the room temperature had risen to 24^{0}C [75^{0}F] with a mercury in air level of 0.45 mg.Hg/m^3air. Prior to entering the room the worker’s overall collar and chest area [these overalls had already been worn for 3 days prior] was “sniffed” with the meter and gave a reading of 0.02 mg.Hg/m^3air.

At the finish of the retort and having been in the room for 1 hour the overall was “sniffed” at the collar level in the outside air and gave a reading of 0.08 mg/m^3air, ½ an hour later the level had dropped to 0.066 mg.Hg/m^3air and by the end of the day still registered a level of 0.02 mg.Hg/m^3air.

This experiment was repeated in a limited way over a period of 1 year at different mine sites and with different workers and, although results varied, contamination was noted, especially around cuffs, chest and collars, the very areas in close contact with a worker’s breathing zone. Levels up to a maximum of 0.08 mg.Hg/m^3air were recorded with a mean of 0.02 mg.Hg/m^3air [n=10]. This contamination of clothing provided a mini–zone or microenvironment that was available to contaminate a worker’s breathing zone when wearing contaminated overalls. This was a source of contamination the wearer was not aware of and continued to contaminate his breathing zone whilst he was wearing them even when away from mercury.

As reported above the provision of safety or protective clothing [PPE] although essential was not always provided by employers and Figs 23-25 p 113, show the percentage of companies [n=25] providing the basic protective equipment of gloves, overalls and masks. Even where supplied some of the clothing/protective equipment was not up to standard and/or was not well maintained.

No company had a policy of ensuring that workers actually used the protective clothing supplied nor was their any compulsion for workers to do so.

In the graphs Figs 23 – 30, n=25 company /mine sites visited.

Fig 23.
% of workers wearing gloves in the gold mining industry.[n=25]

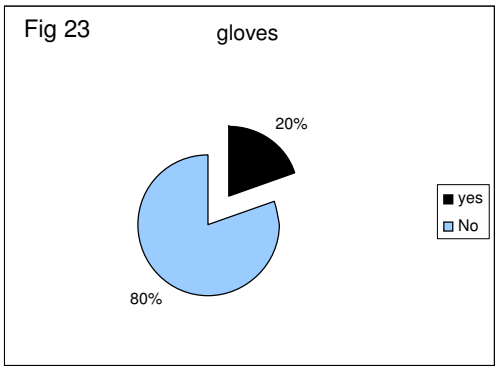


Fig 24.
% of workers wearing masks in the gold mining industry. [n=25]

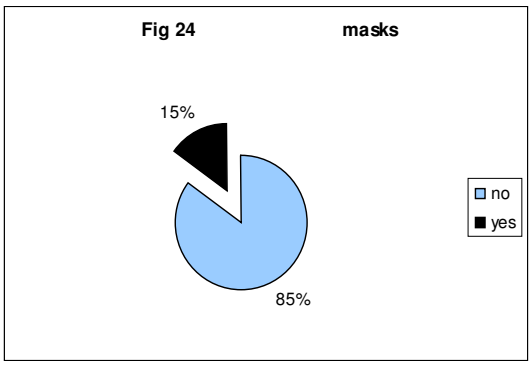
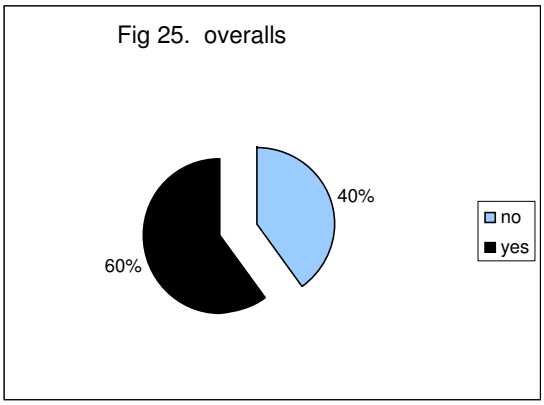


Fig 25.
% of workers wearing overalls in the gold mining industry.[n=25]



11.3. Change rooms/wash rooms.

Change rooms should be supplied for workers to ensure that they have somewhere to store their non-work clothes so that they do not become contaminated by mercury. The washrooms should have hand washing and showering facilities and a means of washing work clothes so that they are not taken home. The change rooms provided at the mining sites visited varied considerably with only a small percentage providing adequate facilities [fig 28 p 116].

11.4. Work rooms.

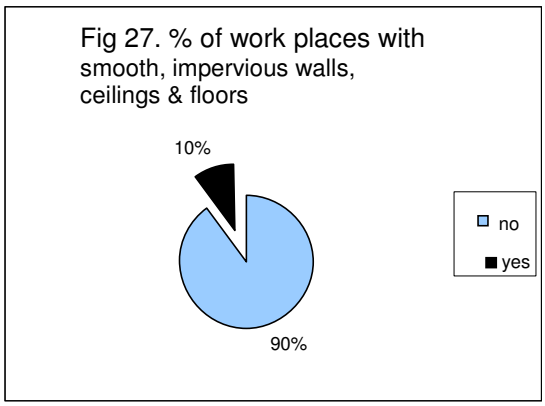
Work room standard generally was poor and reflected the fact that there were no guidelines as to what was an acceptable standard for such buildings [fig 26 & 27 p115]. They were built to be functional with work places used for amalgamation and retorting all of very similar construction, usually involving a corrugated tin shed with roof and outer wall lined with iron and unlined wood framing and ceiling inside. Some floors were of wood but most were of rough concrete and spilt mercury would catch in this rough concrete or in the cracks between wooden floor boards. As noted earlier it is very difficult to pour mercury without splashing or spilling small droplets, many of which are too small to be seen with the naked eye. As these droplets will not agglomerate, decontamination becomes extremely difficult. There is no satisfactory method of preventing spilt mercury from vaporising.

In summer these buildings absorbed heat and acted like ovens with the temperature inside rising very quickly due to the tin cladding, vaporising any spilt or exposed mercury. The mercury adhered to organic materials such as wood, and work surfaces were usually wood or similar pervious material. The poor standard of buildings is reflected in the results of mercury vapour readings discussed further in this document.

Figs 26 to 29 give an indication of the standard of the work places. The level of compliance with these basic requirements was generally very poor and even the 35% recorded as kept clean should have been better.

Fig 26.
% of workplaces kept clean
in the gold mining industry. [n=25]

Fig 27.
% of workplaces with smooth,
impervious walls, ceilings and floors
in the gold mining industry. [n=25]



All work places provided personal washing facilities [toilets and wash-hand basins], but few provided showers [fig 28, p 116] and none provided clothes washing equipment for laundering overalls.

Fig 28.

% of workplaces with showers in the gold mining industry.[n=25]

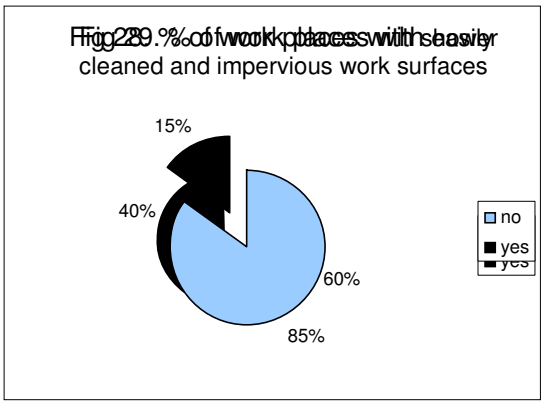


Fig 29.

%of workplaces with easily cleaned, impervious work surfaces in the gold mining industry.[n=25]

11.5. Ventilation.

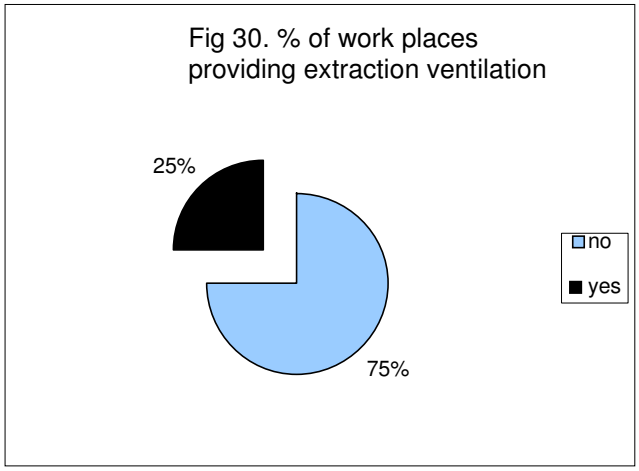
Good ventilation is critical for work places using mercury. The containment and removal of mercury fumes is the first principle of control and prevention of mercury contamination of the workplace. The US Department of Mines suggests a minimum of 40 m/min as a reasonable air velocity where no general room ventilation is provided (personal papers). Some work places [Fig. 30 p 117] had mechanical ventilation, including extraction ventilation over retorts but most relied on natural convection currents via open doors and windows. Where natural ventilation was used smoke tests often showed some areas of still air i.e. no air movement. Air currents short circuited between windows and doors in a direct line leaving pockets of still air in corners and this was often where the retort was situated or mercury vapour accumulated.

Where mechanical ventilation was used, smoke tubes indicated that air was pulled into the extraction fan close to the hood when doors and windows were closed, creating air movement around the room. However, if doors and windows were left open there was a tendency for the air to flow from these openings toward the extraction fan leaving some areas of poor quality air with little to no movement, usually in corners.

Fig 30 shows the percentage of work place ventilation systems [n=25] in operation. Ventilation is an essential part of the protective equipment that should be supplied to prevent build-up of mercury vapour in work rooms and, as can be seen by Fig 30, only 25% of workplaces had any type of forced ventilation. Not all the ventilation systems supplied were 100% effective.

Fig 30.

% of workplaces providing extraction ventilation in the gold mining industry. [n=25]



The effectiveness of the mechanical ventilation depended on the size of the fan used and the design factors of the extraction hood, but not all extraction systems in use had a hood. If a fan was too small, or the extraction hood exhaust pipe too small, the amount of air moved was reduced, or restricted. This affected the efficiency of the system and left areas of the work room where air movement was poor. None of the ventilation systems in operation were designed by ventilation engineers, being usually made by the company staff or bought off the shelf. Measurement of airflow within work rooms in this study was carried out using an anemometer with smoke tubes to indicate current direction and movement. Natural air changes in work rooms were as low as 2 or 3 air changes per hour with air flows between 5 and 8 m/min.

Where fans were in use air flow was measured up to 60 m/min. Unfortunately fans tended to be used only whilst retorting was being carried out and, when turned off, any spilt mercury still in the room continued to vaporise and be available to contaminate workers.

The inefficiency of work place air extraction resulted in high levels of mercury vapour accumulating in work rooms. Visual observation of work places found spilt mercury on floors and bench surfaces with walls having a metallic grey sheen that gave mercury readings when “sniffed” with the meter. The lack of good housekeeping added to these problems, allowing spilt mercury to accumulate and contaminate the workrooms.

As explained before, mercury is very difficult to collect once spilt (US DoL 1985) and the condition of these work places added to this difficulty. If spilt mercury is not cleaned up quickly and completely it will be easily spread round the site. It forms droplets that can accumulate in the smallest of spaces, e.g. cracks in floorboards and concrete.

11. 6. Mercury in air measurement. [Hg–air].

The key to prevention of mercury contamination is reducing the risk of mercury escaping into the environment. Spillage of mercury, poor equipment, sub standard buildings, poor seals on crucibles, poor work practice, storage of mercury contaminated equipment in work rooms, and inadequate ventilation all added to mercury vapour levels in work rooms. Workrooms were often divided into amalgamation and retorting areas and poor ventilation systems, or lack of ventilation, compounded the problem. Most mercury in air measurements were made with the mercury meter with limited grab sampling employed in certain locations.

In most of the systems for setting Occupational Exposure Limits (OEL) two types of limit values are established:

- time weighted average concentrations (TWA), intended to protect all or nearly all workers from adverse health effects of occupational exposure:
- short-term exposure limits (STEL) peak limitations, intended as supplementary to TWA and protecting against short-time effects.

In New Zealand, only TWA is used for mercury measurements as there is no STEL for mercury. The TLV for mercury in air was 0.05 mg/m^3 as a TWA (DOL 1975), and measurement data for the sites are shown in table 4 p123 and table 5 on p 125.

11.6.1. Work room air measurements.

Mercury in air measurements [Hg–air] were monitored at the premises where the employees supplying the urine samples worked. There was some difficulty in obtaining results in this industry because of the way that the work day was structured. Mercury use was not a day long operation and the timing of these varied as the person handling the mercury also performed other tasks. Employees were often required to work in the same room where the mercury handling occurred [multipurpose workrooms] after mercury handling had finished for the day and they could continue to be exposed to mercury vapour. This type of operation leads to peaks and troughs in mercury vapour levels and exposures, so mercury in air grab samples were taken at periods over a work day with statistical evaluation done to give an average that could be compared with the TLV (NIOSH 1975).

Grab sampling enabled an average of a fluctuating daily level to be calculated but, it did not identify peaks unless one occurred during the measurement period and was observed. The intention was that where possible, a mercury in air measurement would be carried out in each work place at the time a urine

sample was collected. In reality only 1 air measurement was carried out for every 5 urine samples collected. As mentioned above the level of vapour in work rooms was directly related to the amount of mercury released by various sources within the room. One source was the use of mercury to recover gold through the retorting process. Other sources involved spilt mercury, contaminated surfaces and equipment, poor workplace hygiene and poor work practices.

As the temperature in work rooms increased a corresponding rise in mercury vapour levels were measured. The vapour pressure of mercury increases rapidly with temperature and enough vapour can be produced at room temperature to contaminate any person in the room. A saturated atmosphere at 20^0C contains approximately 15 mg.Hg/m^3air, 300 times greater than the TLV of 0.05 mg/m^3 (WHO 1990).

Rising room temperatures were brought about by a combination of the heat from the retorts and the building absorbing heat from the sun [S11.4. p 114]. Mercury vapour levels were higher in work rooms, and remained high for longer, in the summer than in winter. This was partly due to the buildings acting like ovens in summer and refrigerators in winter. This is covered further in the discussion section [Chapter 12, p 165].

11.6.2. Non–retort area measurements.

This area was usually separate from the retorting area, although in many cases there were no doors between, and it was here that the gold was cleaned up and mixed with mercury to form an amalgam. The process used water and was partially a wet process. In most sites the floor was wet during the amalgamating work and this reduced the vaporising of spilt mercury. Air measurements within these rooms indicated that the work place did become contaminated by mercury even with this wet area.

Mercury in air measurements [Hg–air] for the non-retort group reflects this use of water on the floor and less contact with mercury. Where air levels were high it reflected the standard of housekeeping and poor ventilation. Limited grab sampling of mercury in air levels were measured in these non–retort areas. From the measurements 5 out of the 8 work rooms tested [63 %] were over the TLV for mercury [0.05 mg./m^3] as an average using NIOSH statistical evaluation criteria (NIOSH 1975). The remaining 3 measurements gave 2 at just below the TLV and 1 equal to the TLV.

The NIOSH [1975] handbook provides an easy to follow procedure for making decisions regarding the average of a time varying industrial contaminant exposure level and whether a non-compliance, or trend, occurs. The procedure is useful where there is no clear trend in the measurements or where it can not be decided whether non-compliance has occurred by looking at the data. The contaminant data in this study are a set of breathing zone

grab air samples from a time varying industrial environment [workrooms]. The measurements are set out as per table 4 below and table 5 [page 125] and, using the steps in the handbook and the nomographs provided with the handbook an average for the collected data was calculated. Individual grab samples of mercury vapour levels [mg.Hg/m^3air] measured at time varying intervals in the non-retort area of mining sites are shown with an average level for the day in table 4 .

Table 4. Individual grab samples taken at time varying intervals [1986-88] of mercury vapour levels [mg.Hg/m^3air] in the non-retort area with an average level for the day. [TLV= 0.05 mg/m^3]

[n=8]

Table 4.										
Time [hrs]:	0800.	0900.	1000.	1100.	1200.	1300.	1400.	1500.	1600.	1700.	Average
Time index:	1	2	3	4		5	6	7	8		[NIOSH]
Work place	mg.Hg/m^3 air										mg.Hg/m^3
1	0.06	0.08		0.13		0.15		0.16			0.11
2	0.03		0.04	0.04			0.1		0.05		0.05
3	0.03		0.04	0.08			0.04		0.03		0.04
4	0.04		0.04	0.12		0.1		0.05			0.07
5		0.01	0.11			0.13	0.09		0.08		0.08
6		0.05		0.05		0.07	0.06		0.03		0.05
7		0.03		0.04		0.07		0.04	0.02		0.04
8	0.02			0.04		0.1		0.1	0.05		0.06

11.6.3. Retort area measurements.

As already mentioned [fig 10 p29] the retort was a cast iron, moulded crucible with a top that contained a water jacket to condense mercury vapour in which the gold/mercury amalgam was heated @ 750^0C–850^0C [1382^0F -1562^0F]. [fig 9 p28]. During a retort the temperature in the room was noticed to rise rapidly with the heat given off from the fire under the retort. In the height of summer the room temperature could exceed 35^0C [95^0F].

Table 5 p125 indicates the grab sample mercury in air levels measured in retorting areas at the mine sites. All 8 work rooms tested [100 %] were above the TLV >0.05 mg/m^3 as an average, using statistical evaluation criteria (NIOSH 1975).

High mercury in air levels in work rooms usually coincided with the retort being operated. In the summer months [the worst case scenario] work rooms had mercury vapour readings above the TLV with high building temperatures vaporising spilt mercury without any retorts operating or mercury being used. When the heat of the retort was added to this naturally created building heat the temperature inside could be very high, in excess of 35^0C [95^0F] being not uncommon.

Mercury in air [Hg–air] measurements from retort rooms confirm that, industry wide, the control of mercury vapour was ineffective. These measurements

were reflected in the urinalysis [Hg–U] results and this is further reinforced by the dosimeter badge results. This is examined further in the discussion in chapter 12.

Table 5.

Individual grab samples taken at time varying intervals [1986-88] of mercury in air levels [mg.Hg/m^3air] in the retort area and showing an average for the day.

[TLV = 0.05 mg/m^3] [n=8]

Table 5.

Time [hrs]	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	Average
Time index:	1	2	3	4		5	6	7	8		[NIOSH]
Work place	mg.Hg/m^3 air										mg.Hg/m^3
1	0.12	0.13		0.41		1.0	0.5	0.2			0.39
2	0.04		0.05	0.26		0.17		0.08	0.07		0.11
3		0.24		0.64		0.71		0.33	0.29		0.37
4	0.03	0.26	0.21			0.10			0.04		0.13
5	0.05		0.23	0.15			0.11	0.09			0.13
6	0.11		0.61			0.36	0.20		0.14		0.28
7	0.21		0.41	0.38		0.3		0.20			0.3
8	0.12	0.14		0.19		0.25		0.23			0.19

The range and mean of all mercury in air [Hg–air] measurements taken at the time of urine collection in 1986–1988 are shown in table 6 p 126. When

the study was planned it was intended that the participant's work place would have a spot air measurement of ½ hour duration at the time his urine sample was collected. This was not a practicable proposition and only a small number of measurements were carried out in this situation [n=32]. The data from these measurements has been condensed to give a range and mean and is included in table 6 below. The data from tables 4 & 5 is not included in this table.

Table 6.

Range and mean of individual mercury measurements [mg.Hg/m^3air] of air samples taken during urine collection in the period 1986-1988 from listed work sites.

[Does not include table 5 & 6 results].

[TLV = 0.05 mg/m^3] [n=32]

Table 6. Workplace site	mg.Hg/m^3 Range	Mean
General work rooms	0.01 - 0.07	0.04
Amalgamating room		
Cold day	0.03 - 0.19	0.12
Hot day	0.06 - 0.24	0.19
Retort room not operating		
Hot day	0.04 - 0.38	0.25
Cold day	0.03 0.17	0.1
Retort room operating	0.16 - > 1.0 **	0.7

**this was the detection limit of the hand held meter.

11.6.4. Breathing zone monitoring.

Mercury dosimeter badges [Fig.21 p102] were used to obtain worker's total exposure to mercury vapour during a working day. They were worn on the lapel of the overalls as close as possible to the mouth [breathing zone.] Because they were in limited supply, only 10 were used in this study. Obtaining a meaningful time scale of exposure with these badges was difficult as the wearer often moved in and out of the mercury zone. This limited monitoring [table 7 below] does indicate that worker exposure levels were too high. The mean of the 10 samples from different employees is 0.136 mg.Hg/m^3air with the highest level being 0.61 mg.Hg/m^3air [TLV = 0.05mg/ m^3].

Table 7.

Dosimeter results using lapel badges [sorbent type] with range and mean of measurements [mg.Hg/m^3air] in period 1986-88.

[TLV = 0.05 mg/m^3] [n=10].

Table 7. Number of samples:	range mgHg/m^3air	Mean mgHg/m^3air
10	0.03 – 0.61	0.136

Time period = 4 hours monitoring per person per day [8 hour work day].

Personal monitoring using lapel badges gave an indication of a person's total daily load but no indication of peak loads. It is possible that large concentrations of vapour, such as that released on opening a retort, could overload the personal monitoring device so that they only reflected that peak and not the total daily load. This was an acknowledged limitation in using these badges and there was no way of recording such incidents unless the wearer was under observation whilst wearing the badge.

As the number of badges available was limited the hand held meter and Dräger adsorption tubes were also used for breathing zone measurements. Observation of the retorting process had noted that when the retort was opened a grey vapour was given off. The meter recorded this fume as mercury vapour but the level went off screen due to overload of the meter [>1mg/m^3]. Using the Dräger tubes to give instant readings at crucible opening times, levels as high as 2 mg.Hg/m^3air were recorded. However, this was the top of the range for these tubes so the level could have been higher [see table 1 p 47].

11.7. Off site contamination.

Mercury contamination can also be transferred to other work places where workers may be unaware that they are at risk. Spilt mercury, not cleaned up immediately was spread around the site via footwear. The contaminated footwear transferred the mercury to other areas of the work site e.g. offices, vehicles and even lunch rooms. Once the author became aware of the

footwear transfer of mercury from room to room a series of air measurements were carried out in a carpeted office [where a secretary/receptionist was based] of a company that did retorting & amalgamation for other miners. Hg–air levels of 0.035 mg.Hg/m^3air were measured at a height of 200 mm above the carpet. Based on this result a limited number of workrooms at other sites that were thought to be free of mercury, including lunch rooms, were measured and found to have significant levels on warm days. A number [n=16] of non-mercury workplaces were measured over 1 year and the concentration of Hg–air in these rooms ranged from 0.023 - 0.15 mg.Hg/m^3air with a mean 0.085 mg.Hg/m^3air [table 8]. This was over the 0.05 mg/m^3 limit of the workplace TLV set in the standards and these rooms were supposed to be mercury free.

Table 8. Non- workroom mercury in air measurement levels 1987.

n=16. [8 change rooms & 8 lunch rooms].

Site	Range. mg.Hg/m^3air	Mean. mg.Hg/m^3air
Lunch room	0.023 – 0.09	0.06
Change room	0.08 – 0.15	0.085

The longer people breathe contaminated air, the greater the risk to their health. Metallic mercury and its vapours are extremely difficult to remove from clothes, furniture, carpet, and other porous items. If these items are not properly removed, or cleaned, mercury will remain for long periods and continue to be a health hazard to anyone in the room. An example of this was carpet causing a problem in an office where it continued to give off mercury despite attempts at cleaning. Eventually it had to be replaced because of the difficulty in removing all traces of mercury trodden in.

11.8. Mercury in urine [Hg–U].

Mercury in urine [Hg-U] levels are directly related to the level of mercury a person has been exposed to and is a good indicator of past work practice. The urine sampling programme in this study was carried out in line with the conditions of Piotrowski (1975) and National Health Institute [NHI] guidelines, giving results that are meaningful and, in conjunction with my discussions, reinforces the conclusions reached. Urine levels are shown in Figs 33-40 pp134-141 and Figs 42-49 on pp144-151.

11.8.1. Biological Exposure Indices [BEI].

The New Zealand Department of Labour BEIs are reference values used as guidelines for the evaluation of occupational exposure within the New Zealand work force (OSH 1994). They are adopted from ACGHI published data.

> *BEIs are health based values that are established by committees that review existing published and peer-reviewed literature in various scientific disciplines (e.g., industrial hygiene, toxicology, occupational medicine, and epidemiology). Based on the available information they formulate a conclusion on the level of exposure that the typical worker can experience without adverse health effects. The BEIs represent*

conditions under which health authorities believe that nearly all workers may be repeatedly exposed without adverse health effects.

They are not fine lines between safe and dangerous exposures, nor are they a relative index of toxicology. BEIs are not quantitative estimates of risk at different exposure levels or by different routes of exposure. They are based solely on health factors with no consideration given to economic or technical feasibility (ACGIH 2008)

Biological monitoring of exposure to chemicals in the workplace is an important component of exposure assessment and prevention of adverse health effects. During this study biological monitoring was employed in conjunction with ambient air monitoring to provide information on the worker's absorbed dose of mercury and the effect of all routes of exposure.

At the time of this study [1984-1988] the New Zealand BEI for metallic mercury was 0.25 µmol/L. The Action level, [the level at which some action needed to be taken to reduce personal levels] was >0.25 µmol/L; and the Suspension level [the level at which the employee is suspended from working with mercury until their body burden falls] was > 0.5 µmol/L (DOL 1974).

11.8.2. Non–retorters.

From January 1986 to June 1988 a group of employees [n=8] who handled mercury but did not do retorting, were chosen to be participants in the study. Each one was from a different company and they were classed as non–retorters to identify them from those who did retorting. Over the period of the study [2.5 years] each participant gave 24 hour urine samples at an average 4 monthly interval. The lowest Hg–U level for this group was 0.05 µmol/L and the highest was 0.19 µmol/L, with a mean of 0.075 µmol/L [Fig. 31 p 133].

This group remained below the action level of >0.25 µmol/L for the study period. Fig 31 includes the historical sampling carried out over the 1984/1985 period as well as those samples collected from participants in the study 1986 - 88. The graph gives an indication of the industry wide situation. The levels reflect the lower exposure to mercury of this group of participants.

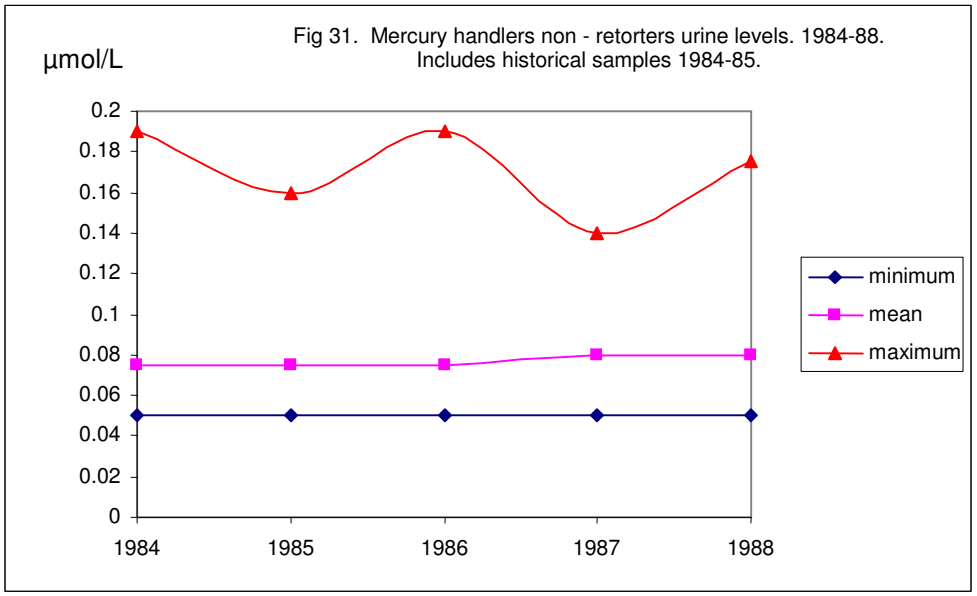
The 8 participants in the urinalysis testing supplied 7 samples each over the period [2.5 years] and were identified by a code [#A, #B, etc.] to ensure anonymity. This code letter appears on the individual's graph and was used on all data collected in the study for that person.

Fig 31.

Graph of the group mean, minimum and maximum levels of all non-retorting mercury handler's urinalysis over the period 1984-1988 [includes historical samples 1984-85].

n= total samples collected.

[n=77] [µmol/L]



1984 n=10. 1985 n=11. 1986 n=24. 1987 n=24. 1988 n=8.

Fig 31 graphs the non-retorting mercury handler's total samples as a group and indicates that they were all below the Action level of > 0.25 µmol/L.

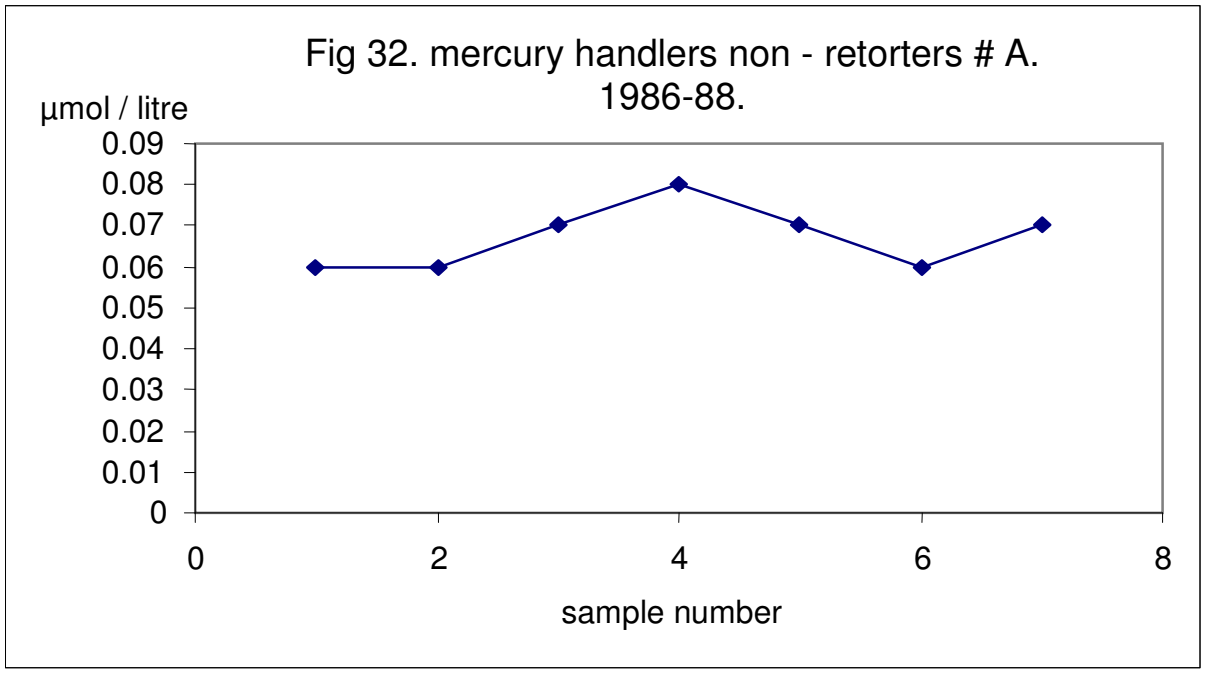
The individual non–retort participant's mercury urinalysis levels that are part of fig 31 from January 1986 to June 1988 are shown in figs 32- 39 pp 134-141. The 1984 and 1985 levels in fig 31 are historical and not included in the individual graphs.

Fig. 32.

Graph of individual non–retort participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = total number of samples for period.

Mean for period 1986 -88 = 0.067 µmol/L. [n=7]



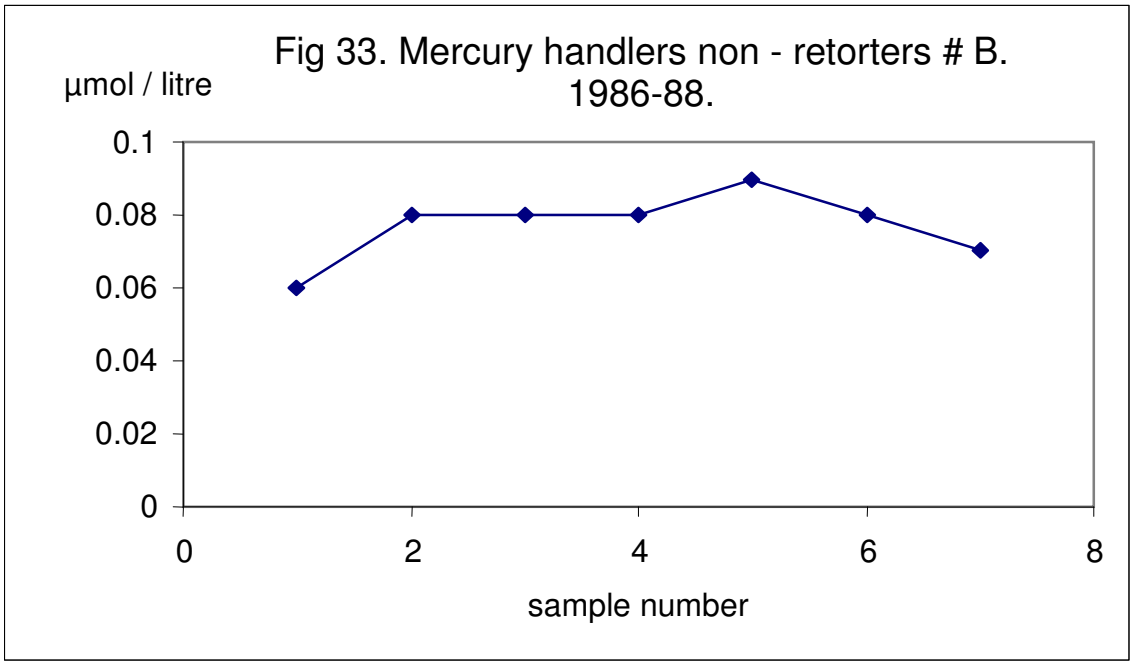
All this participant's samples were below the Action level> 0.25 µmol/L.

Fig 33.

Graph of individual non–retort participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = total number of samples for period.

Mean for period 1986 -88 = 0.073 µmol/L [n=7]



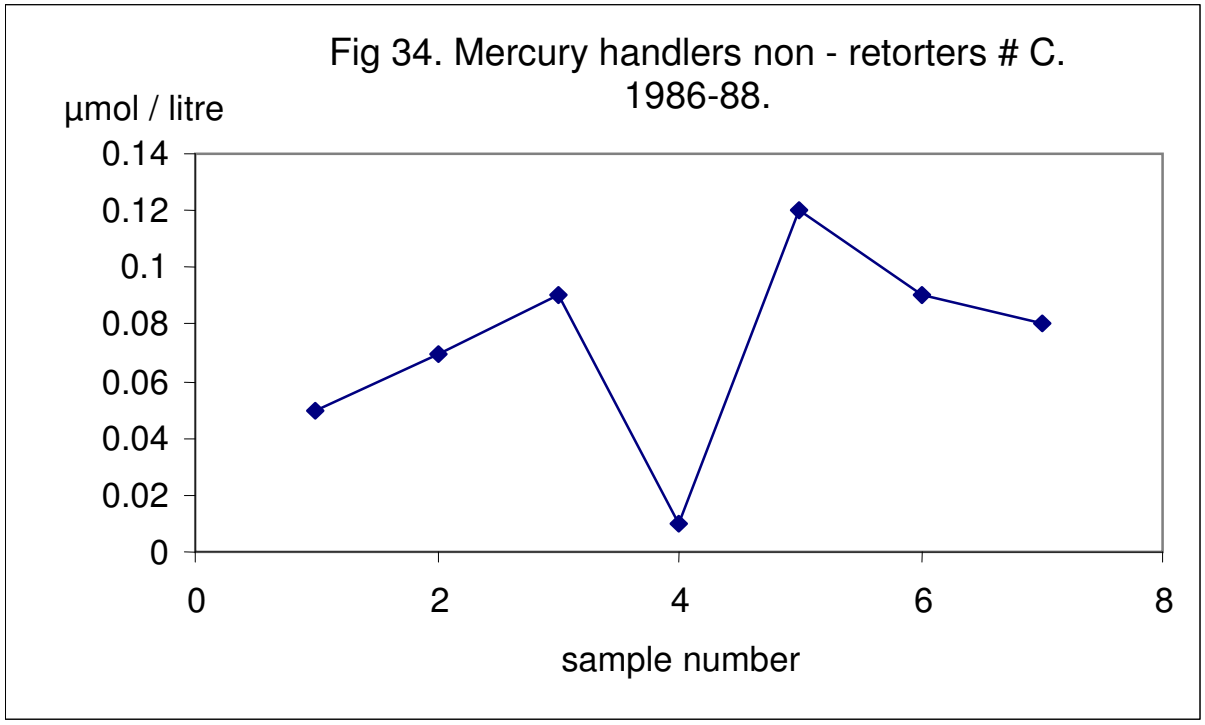
All this participant's samples were below the Action level >0.25 µmol/L.

Fig 34.

Graph of individual non–retort participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = total number of samples for period.

Mean for period 1986 -88 = 0.069 µmol/L [n=7]



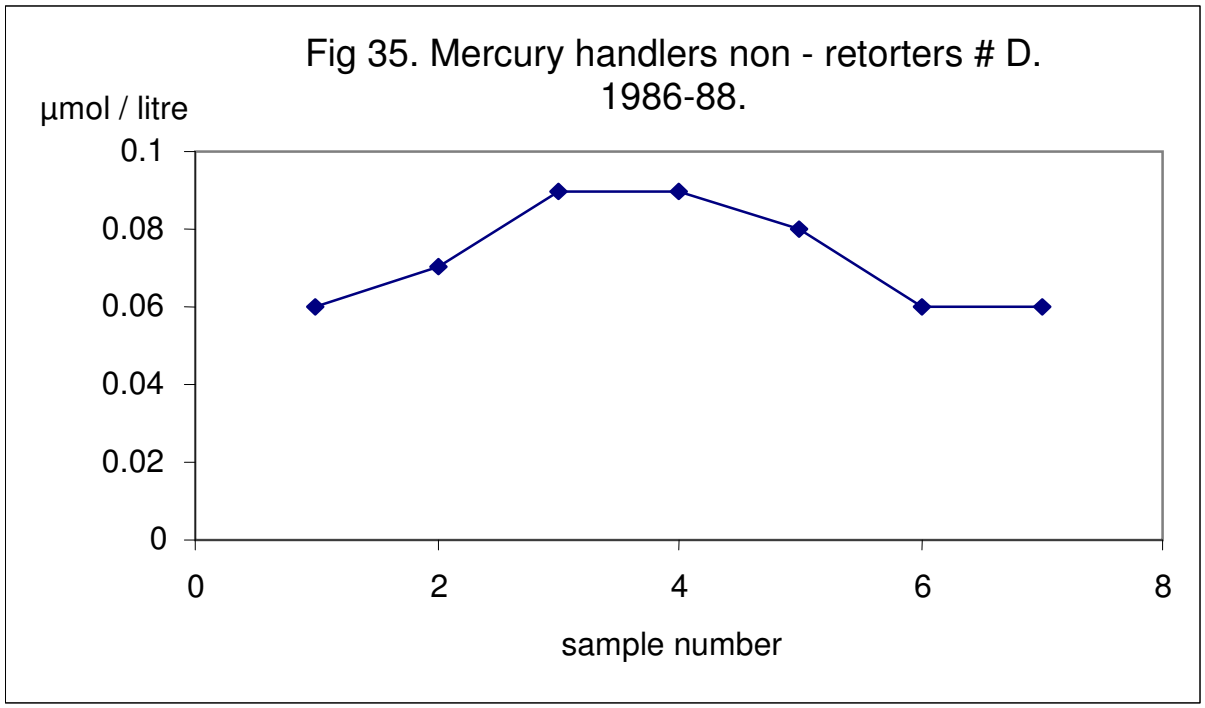
All this participant's samples were below the Action level >0.25 µmol/L.

Fig 35.

Graph of individual non–retort participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = total number of samples for period.

Mean for period 1986 -88 = 0.073 µmol/L [n=7]



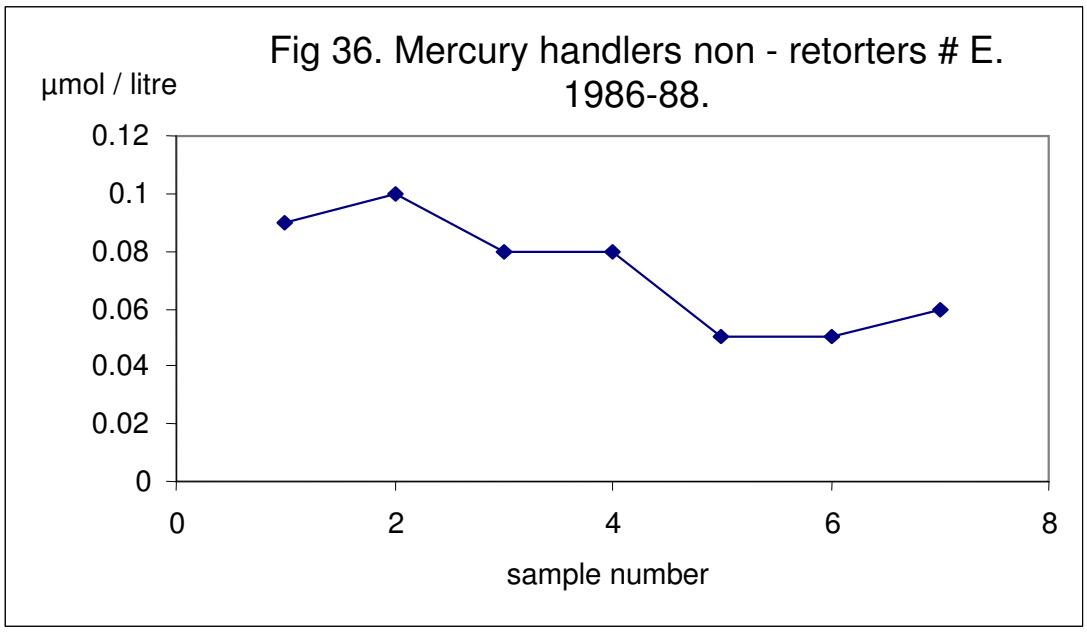
All this participant's samples were below the Action level >0.25 µmol/L.

Fig 36.

Graph of individual non–retort participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = total number of samples for period.

Mean for period 1986 -88 = 0.069 µmol/L [n=7]



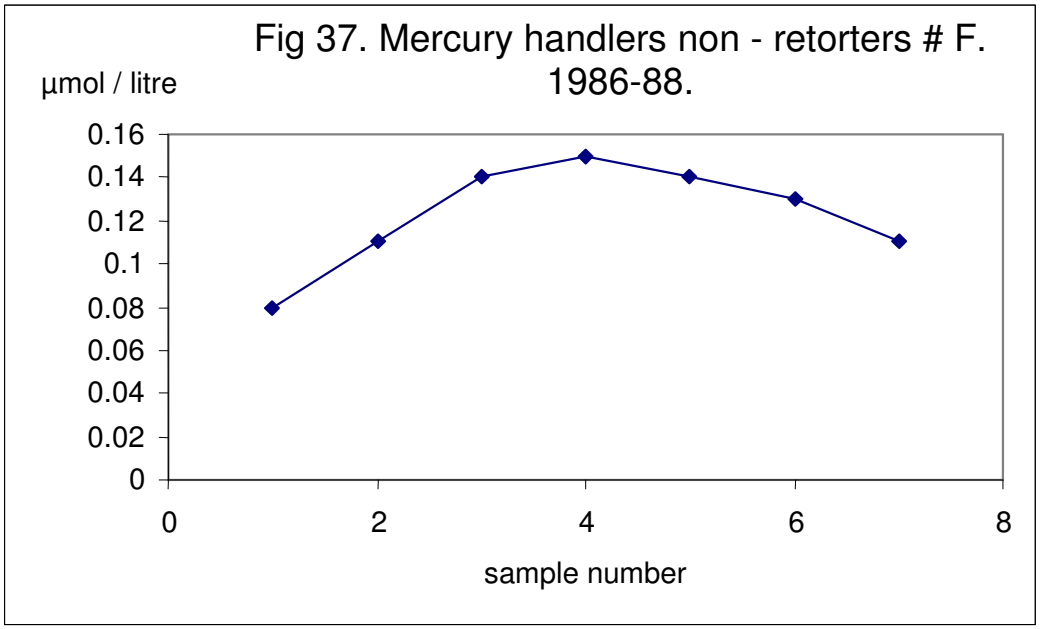
All this participant's samples were below the Action level >0.25 µmol/L.

Fig 37.

Graph of individual non–retort participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = total number of samples for period.

Mean for period 1986 -88 = 0.12 µmol/L [n=7]



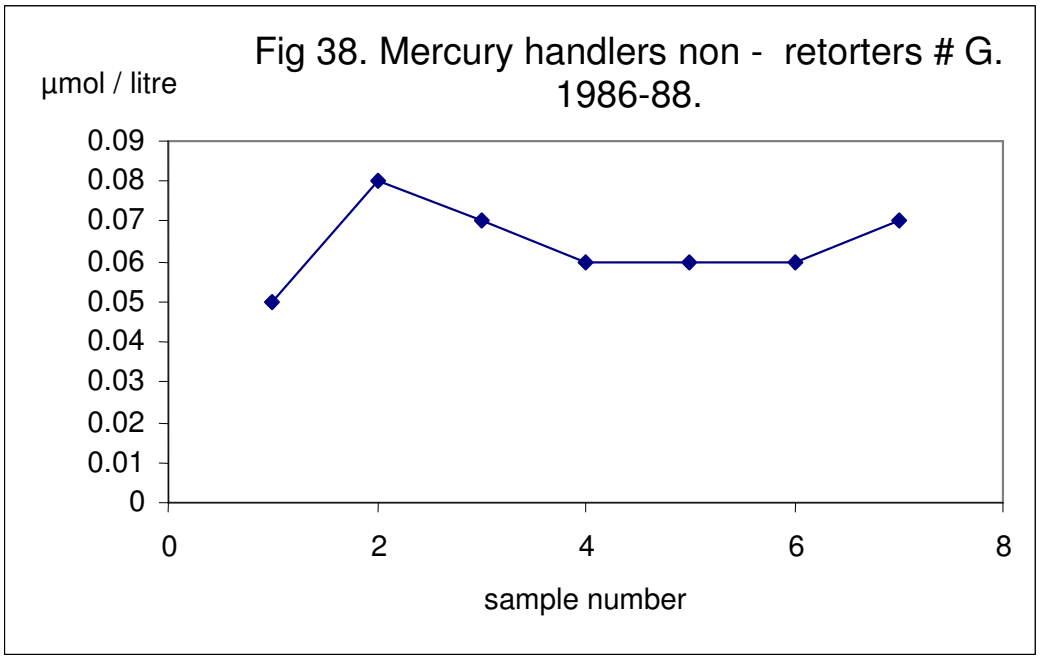
All this participant's samples were below the Action level >0.25 µmol/L.

Fig 38.

Graph of individual non–retort participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = total number of samples for period.

Mean for period 1986 -88 = 0.064 µmol/L [n=7]



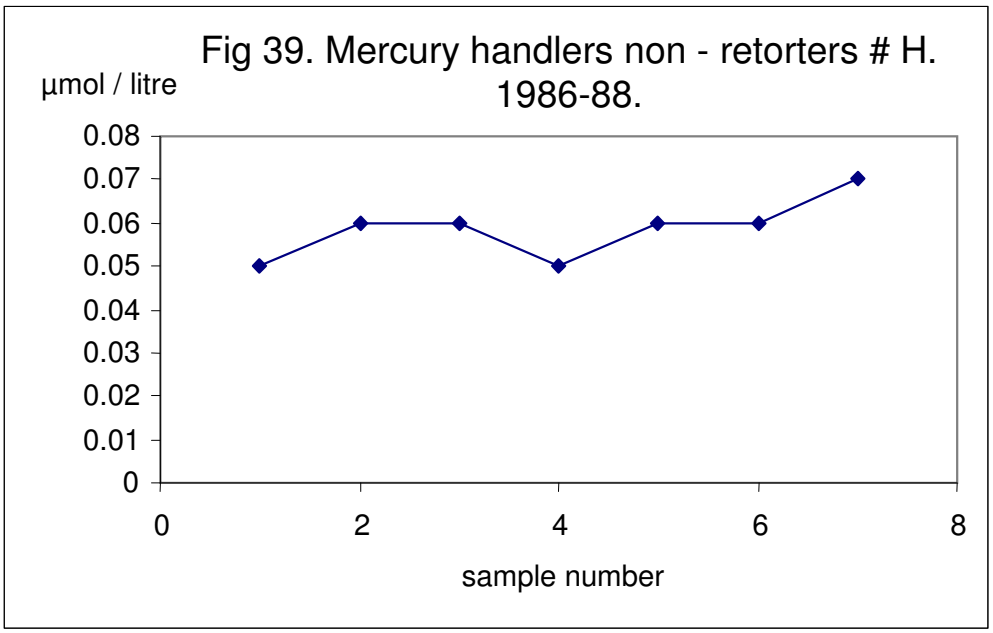
All this participant's samples were below the Action level >0.25 µmol/L.

Fig 39.

Graph of individual non–retort participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = total number of samples for period.

Mean for period 1986 -88 = 0.059 µmol/L [n=7]



All this participant's samples were below the Action level >0.25 µmol/L.

Individual urinalysis [Hg–U] from the non–retorting mercury handlers gave levels below the BEI [page 130]. These were comparable as a group [Fig 31 p133] with the control group [Fig 52 p

155] however, the mean was slightly higher. On an industry basis the results in Fig 31 indicates that the group mean is below the guideline level and close

to the norm of the control group. This reflects the lower level of contact with mercury by this non-retort group.

11.8.3. Retort operators.

From January 1986 to June 1988 a group of employees [n=8] who were responsible for retorting, were chosen to be participants in the study. They were from different companies to the non–retorters and they were classed as retorters as a means of identification. This group had more contact with mercury vapour than the non-retort group and this is reflected in their urine levels.

The retort group urine analysis levels over the period 1986-88 [n=58] with 1984-85 levels [n=20] included, are shown in Fig 40 p 143. The lowest level for this group was 0.05 µmol/L and the highest was 3.2 µmol/L, with a variable mean year to year of 0.25 µmol/L to 0.9 µmol/L. The BEI was exceeded by all 1986-88 participants at some stage of the study with 4 out of the 8 being above the Suspension level of >0.5 µmol/L at various times with the remaining 4 being above the Action level of >0.25 µmol/L. The 1986-88 levels are in the individual participant's graphs in Figs 41-48 pp 144 – 151.

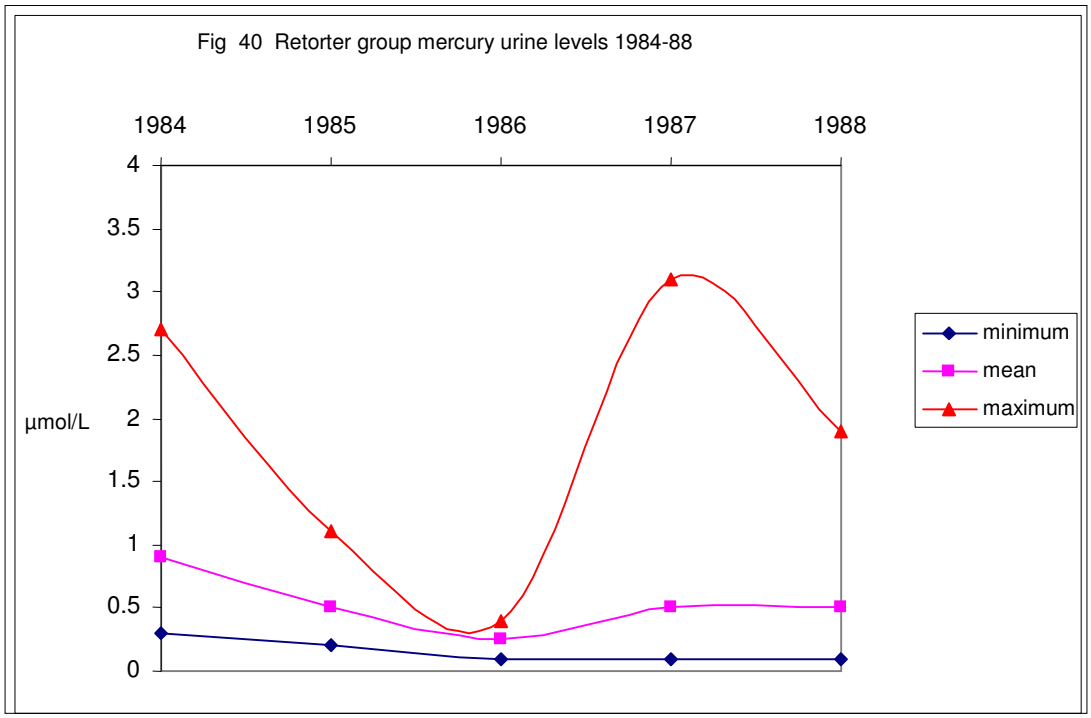
Total sample results taken [n=78] in period 1984-88 inclusive of historical samples as per the group graph in Fig 40 p143 gave:

- Suspension level [>0.5 µmol/L] 228/78 = 36% above;
- Action level [>0.25 µmol/L] 28/78 = 36% above;

Fig 40.

Graph of the group mean, minimum and maximum urinalysis levels for the retorting mercury handlers in the 1984-1988 period [includes historical samples 1984-85].

n= total samples collected.



1984 n=10. 1985 n=10. 1986 n=24. 1987 n=24. 1988 n=10

Fig 40 includes the historical samples 1984-1985 and the participants from 1986-1988.

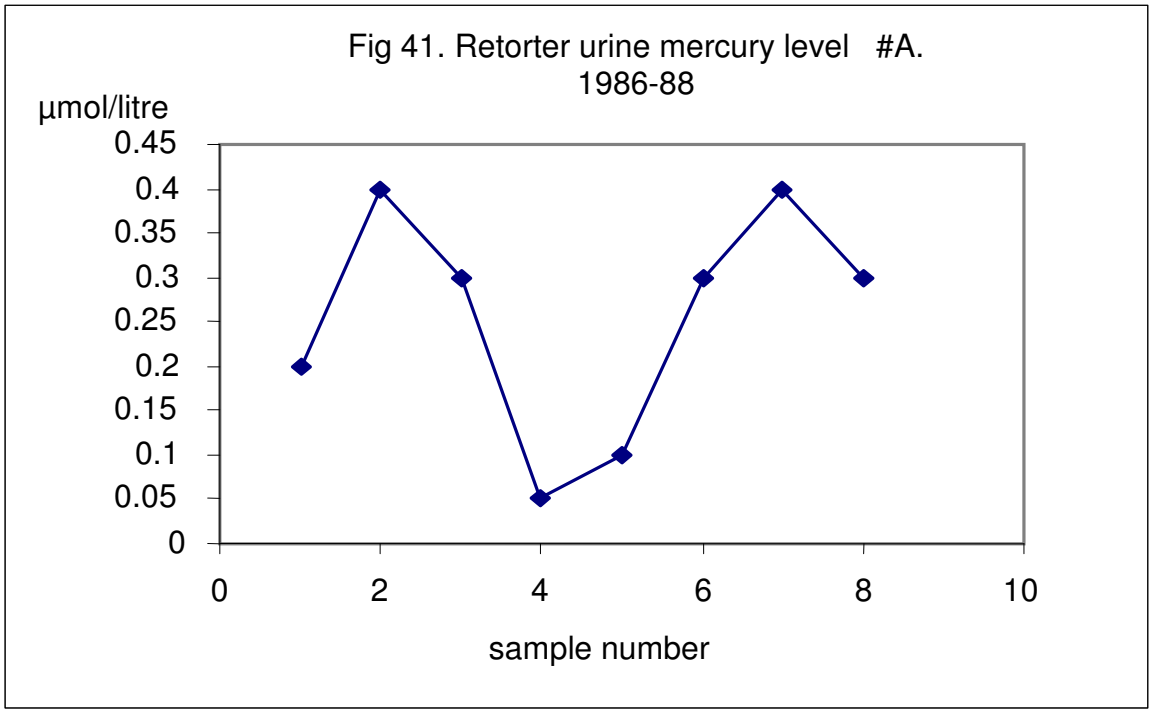
Figs 41 to 48 pp 144-151 show the results of the individual retort operator's urinary mercury levels collected during the study 1986-88.

Fig 41

Graph of individual retorting participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = Total number of samples taken over period 1986-88.

Mean for period = 0.26 µmol/L [n=8]



No samples were above the Suspension level [>0.5 µmol/L].

5 out of the 8 samples were above the Action level [>0.25 µmol/L]

3 out of 8 samples were below the Action level.

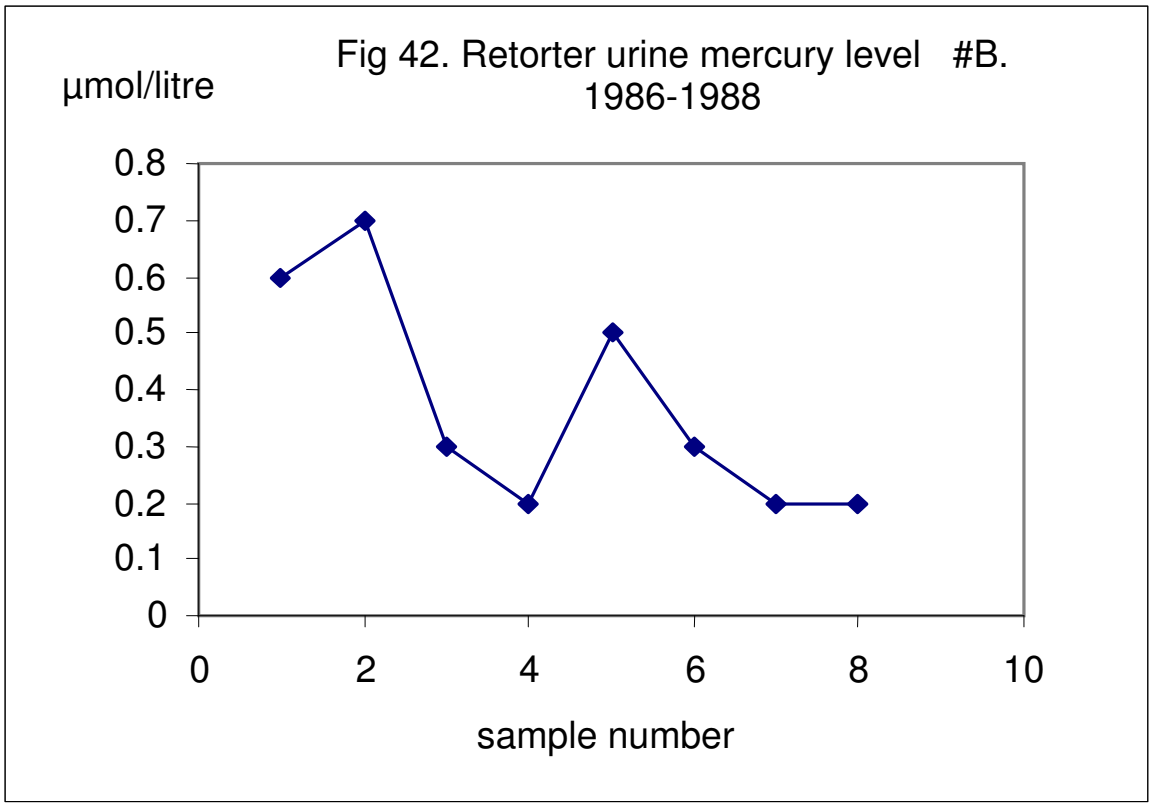
The mean was above the Action level.

Fig 42.

Graph of individual retorting participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = Total number of samples taken over period 1986-88.

Mean for period = 0.38 µmol/L [n=8]



2 out of 8 samples were above the Suspension level [>0.5 µmol/L].

3 out of 8 samples were above the Action level [>0.25 µmol/L].

3 out 8 samples were below the Action level.

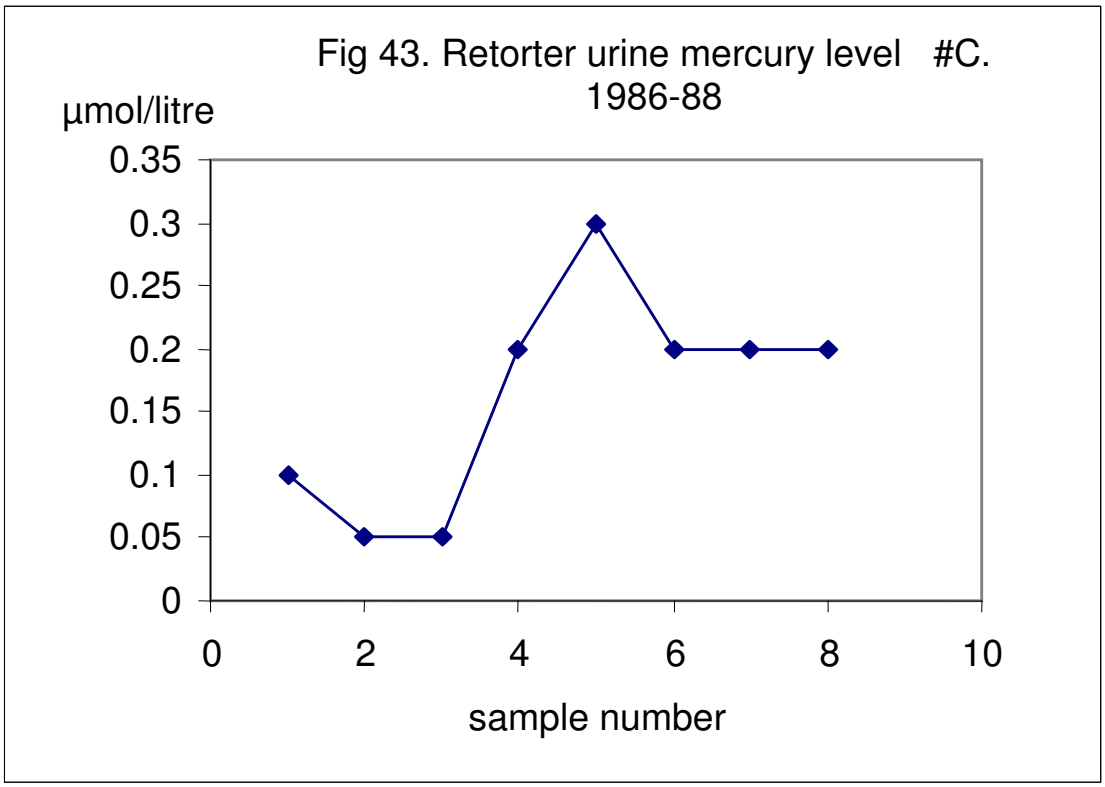
The mean was above the Action level.

Fig 43.

Graph of individual retorting participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = Total number of samples taken over period 1986-88.

Mean for period =0.19 µmol/L [n=8]



No samples were above the Suspension level [>0.5 µmol/L].

1 out of 8 samples were above the Action level [>0.25 µmol/L].

7 out of 8 samples were below the Action level.

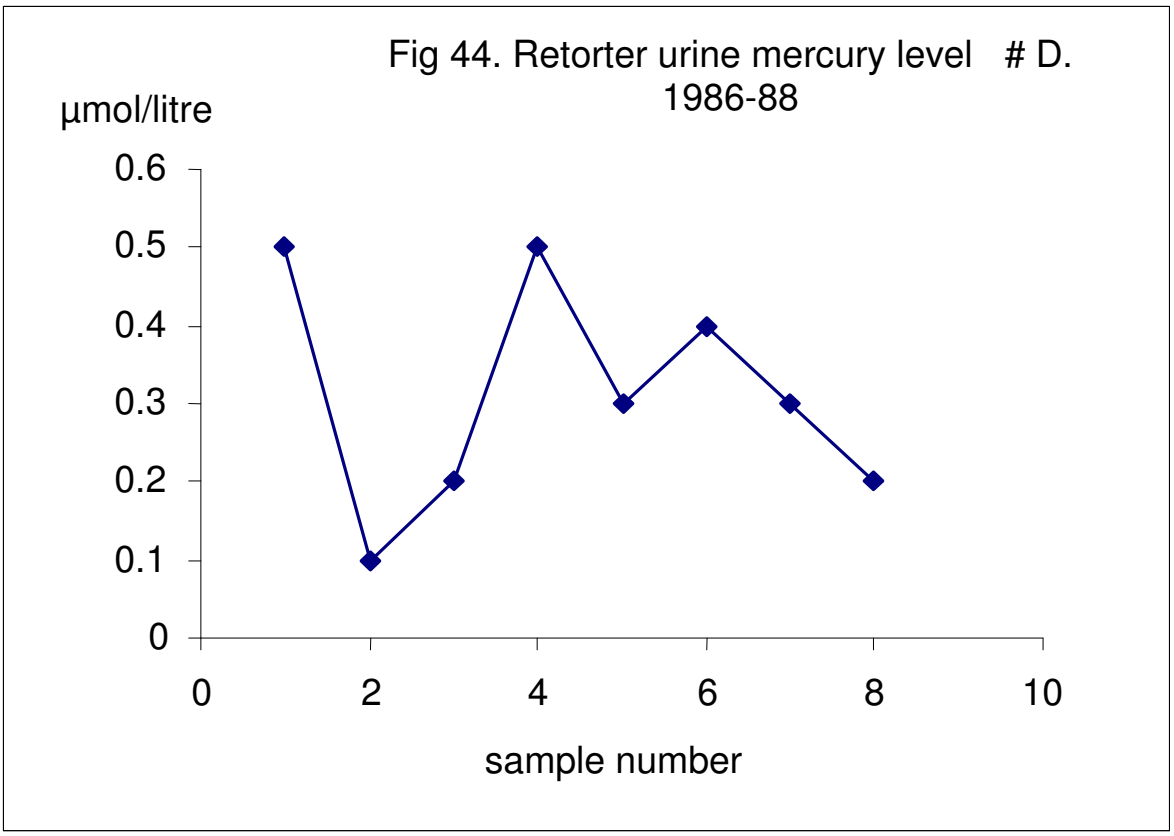
Mean was below Action level.

Fig 44.

Graph of individual retorting participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = Total number of samples taken over period 1986-88.

Mean for period =0.31 µmol/L [n=8]



5 out of 8 samples were above the Action level [>0.25 µmol/L].

3 out of 8 samples were below the Action level.

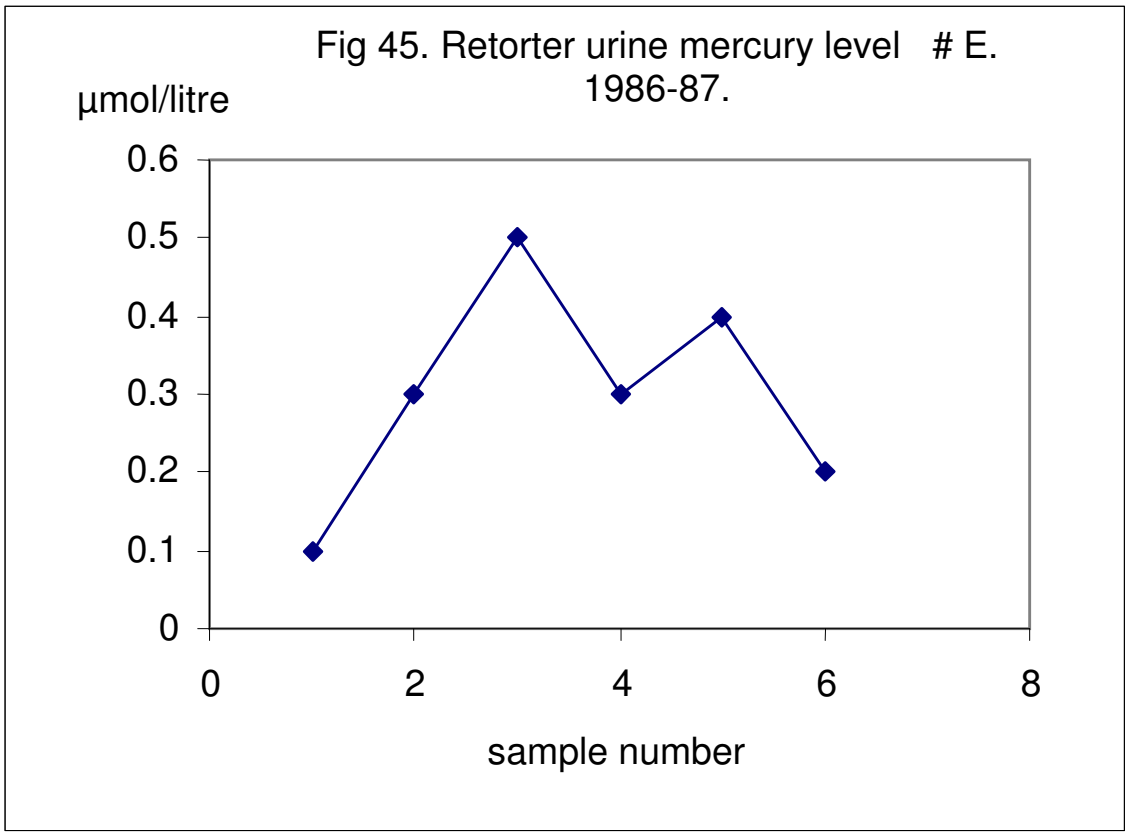
The mean was above the Action level.

Fig 45.

Graph of individual retorting participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = Total number of samples taken over period 1986-88.

Mean for period = 0.3 µmol/L [n=6]



4 out of 6 samples were above the Action level [>0.25 µmol/L].

2 out of 6 samples were below the Action level.

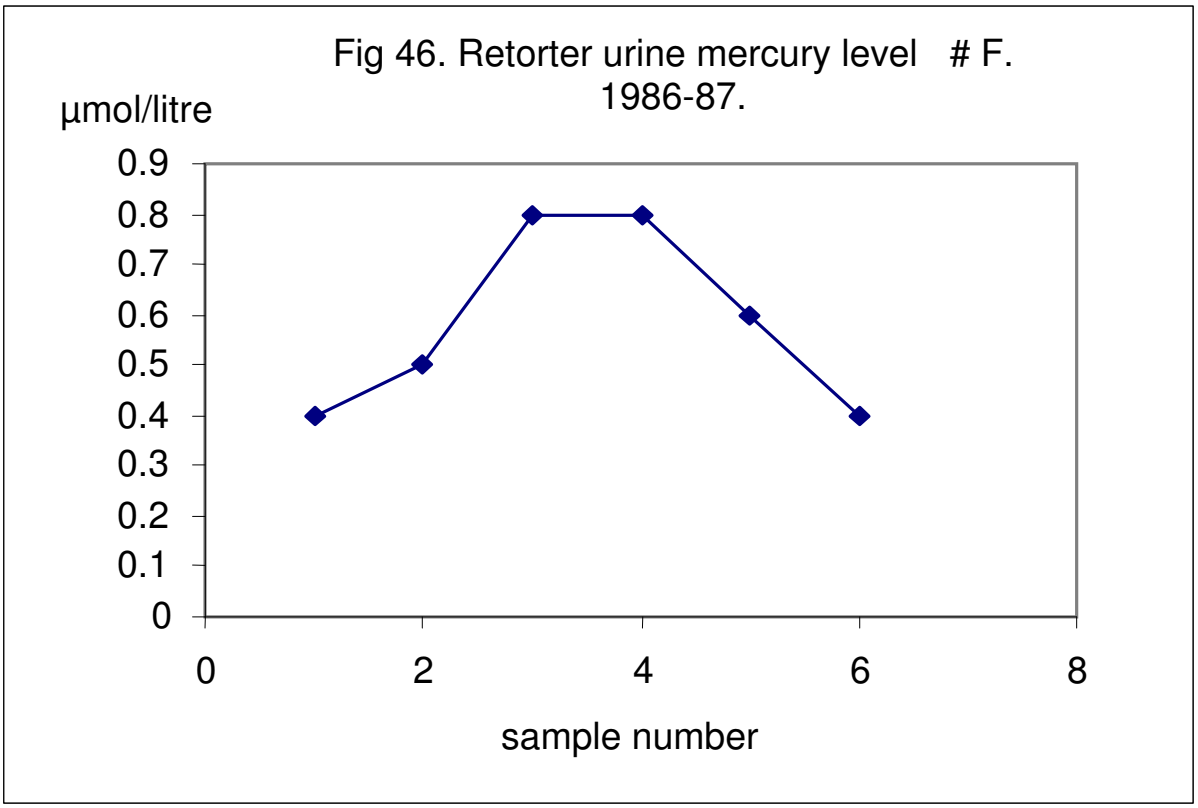
The mean was above the Action level.

Fig 46.

Graph of individual retorting participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = Total number of samples taken over period 1986-88.

Mean for period = 0.58 µmol/L [n=6]



3 out of 6 samples were above the Suspension level [>0.5 µmol/L].

3 out of 6 samples were above the Action level [>0.25 µmol/L].

No samples were below the Action level.

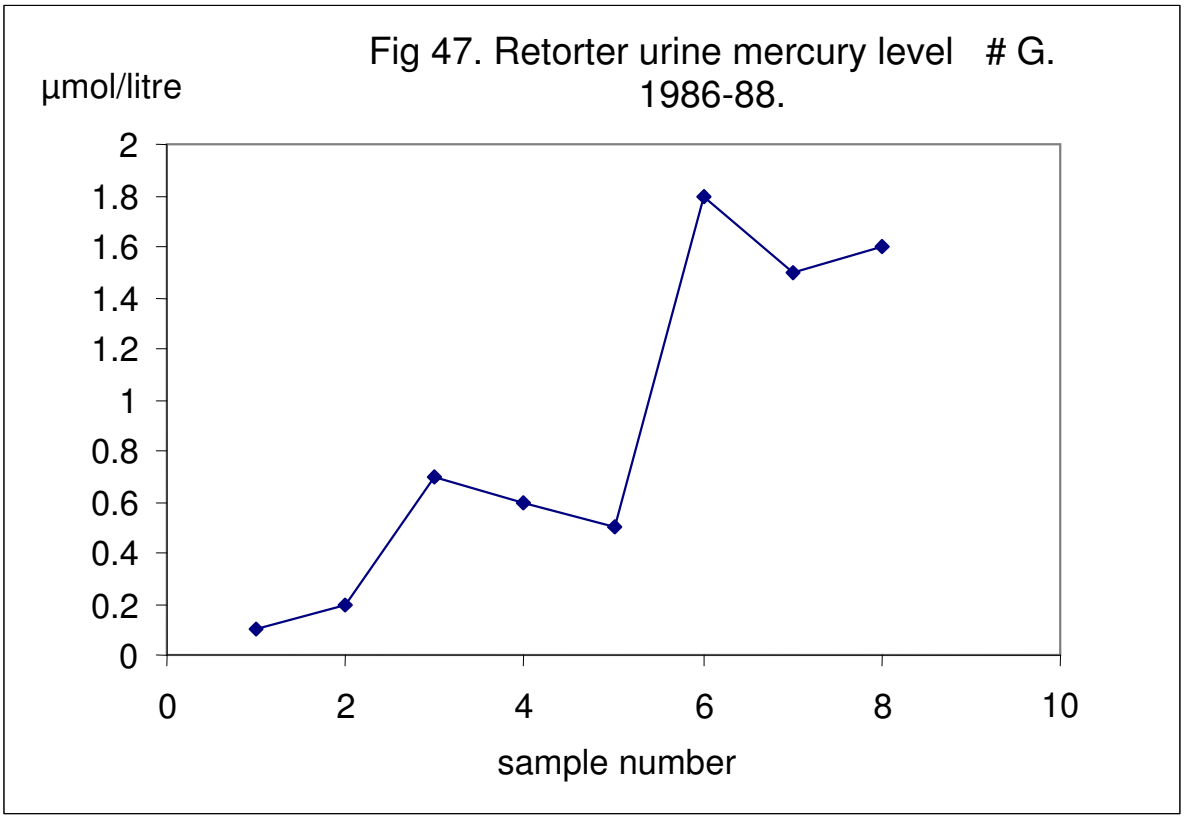
The mean was above the Suspension level.

Fig 47.

Graph of individual retorting participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = Total number of samples taken over period 1986-88.

Mean for period = 0.89 µmol/L [n=8]



5 out of 8 samples were above the Suspension level [>0.5 µmol/L].

1 sample was above the Action level [>0.25 µmol/L].

2 out of 8 samples were below the Action level.

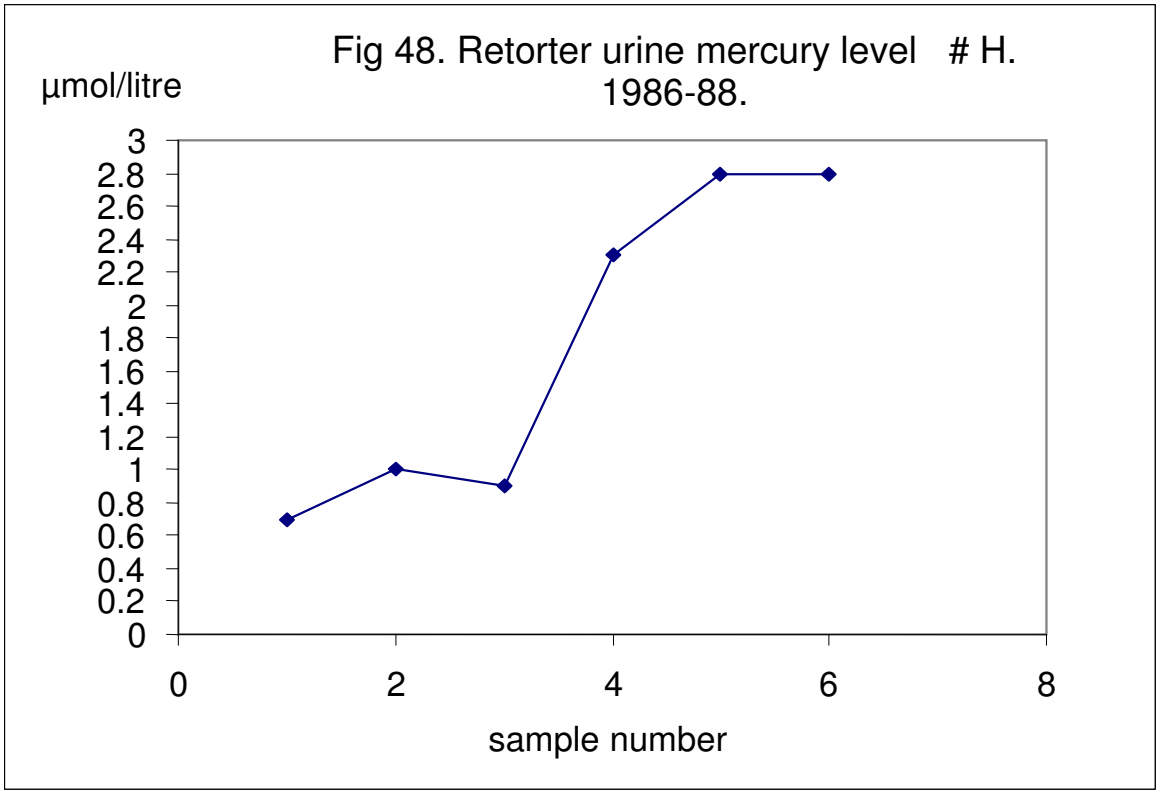
The mean was above the Suspension level.

Fig 48.

Graph of individual retorting participant's mercury urinalysis [Hg–U] January 1986 to June 1988.

n = Total number of samples taken over period 1986-88.

Mean for period =1.57 µmol/L [n=6]



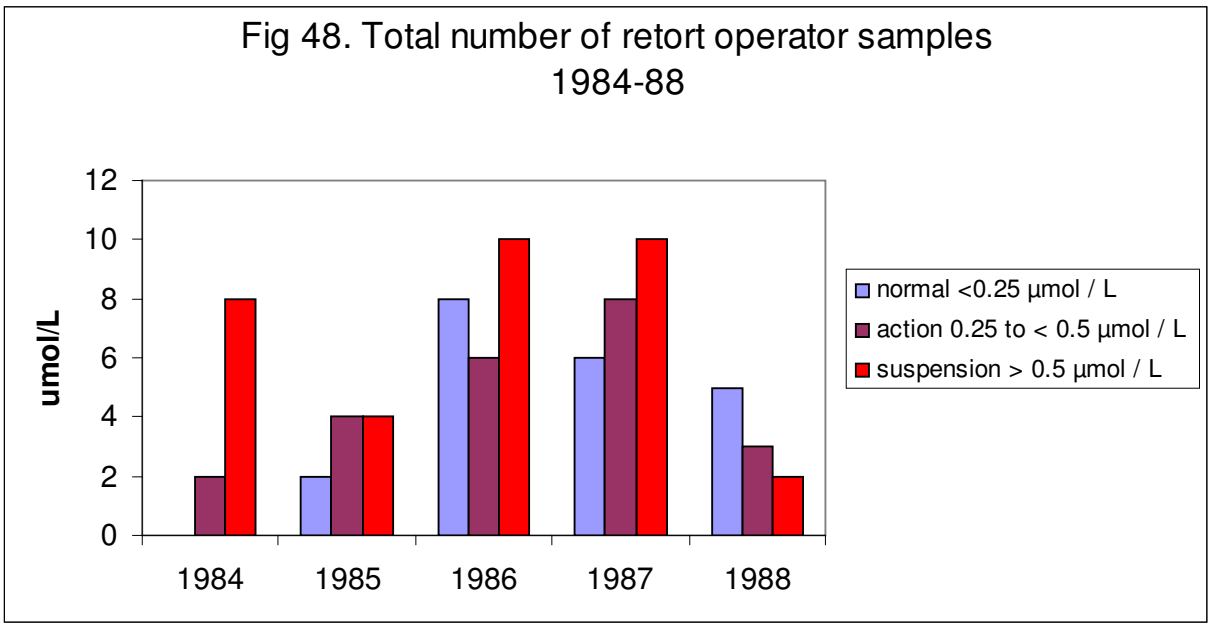
6 out of 6 samples were above the Suspension level [>0.5 µmol/L].

The mean was above the Suspension level.

The urinalysis results indicate that where individuals were monitored on a regular basis over a period of time, their [Hg-U] were high. When Fig. 40 p143 is compared with the controls, Fig 52 p 155, they were well above the norm. The mean of the individual urinalysis were, in the majority of cases, in the Action level range or above the Suspension level, some were very high.
When used to assess occupational exposure on an industry basis, the urinalysis results for the retort operators with a mean above the New Zealand OSH guideline levels [BEI], indicates that the control methods in use were ineffective in protecting workers from mercury contamination. On a group basis the mean should be much lower if safety precautions and protective methods are working.

Fig 49.

This graph indicates the BEI Normal, Action and Suspension levels measured for retort operators in µmol/L for the period 1984-1988 and total number [n] of samples /year. [includes 1984-85 historical data].



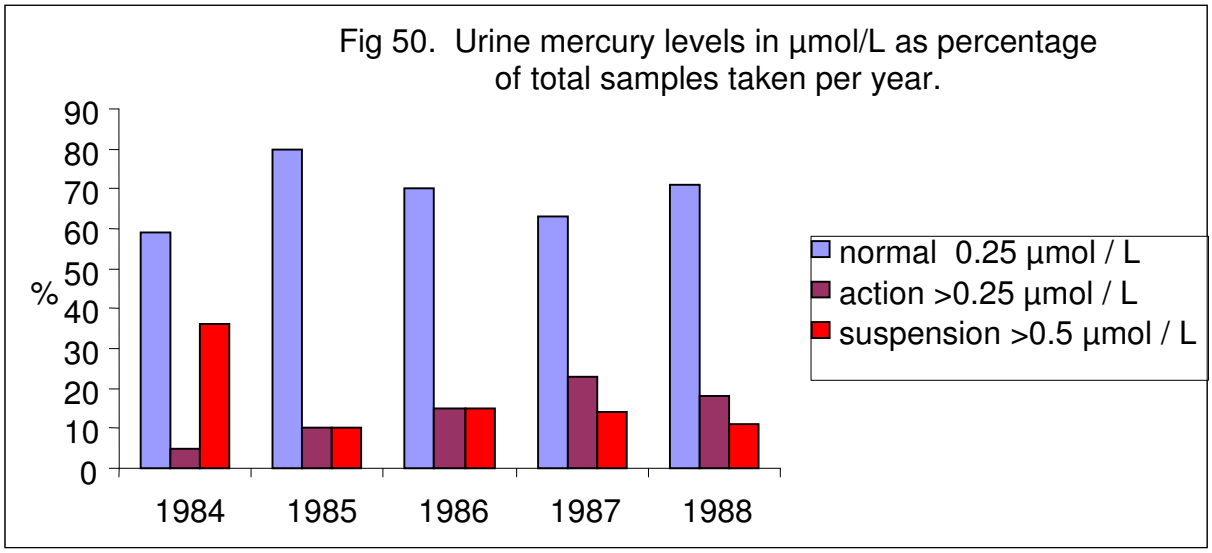
1984 n = 10; 1985 n =10; 1986 n = 24; 1987 n = 24; 1988 n = 10

N.B. No graph has been created for the non-retorters as they were all below the Action level [>0.25 µmol/L].

In Fig 49, 1984 showed high levels with all samples indicating Action level [>0.25 µmol/L] or Suspension level [>05 µmol/L] categories. In the following years there is a mix of categories but predominately in Action and Suspension levels. Given the risks from mercury poisoning these levels are too high. These figures reinforce the ambient air measurements, personal dose measurements and microenvironment measurements that are included in the discussion section [Chapter 12 p 160].

Fig 50.

Graph of the percentage of total urine sample analysis in µmol/L for all study participants [retort operators and non–retort mercury handler's] 1984-1988. [Controls not included but historical data from 1984-85 is included].

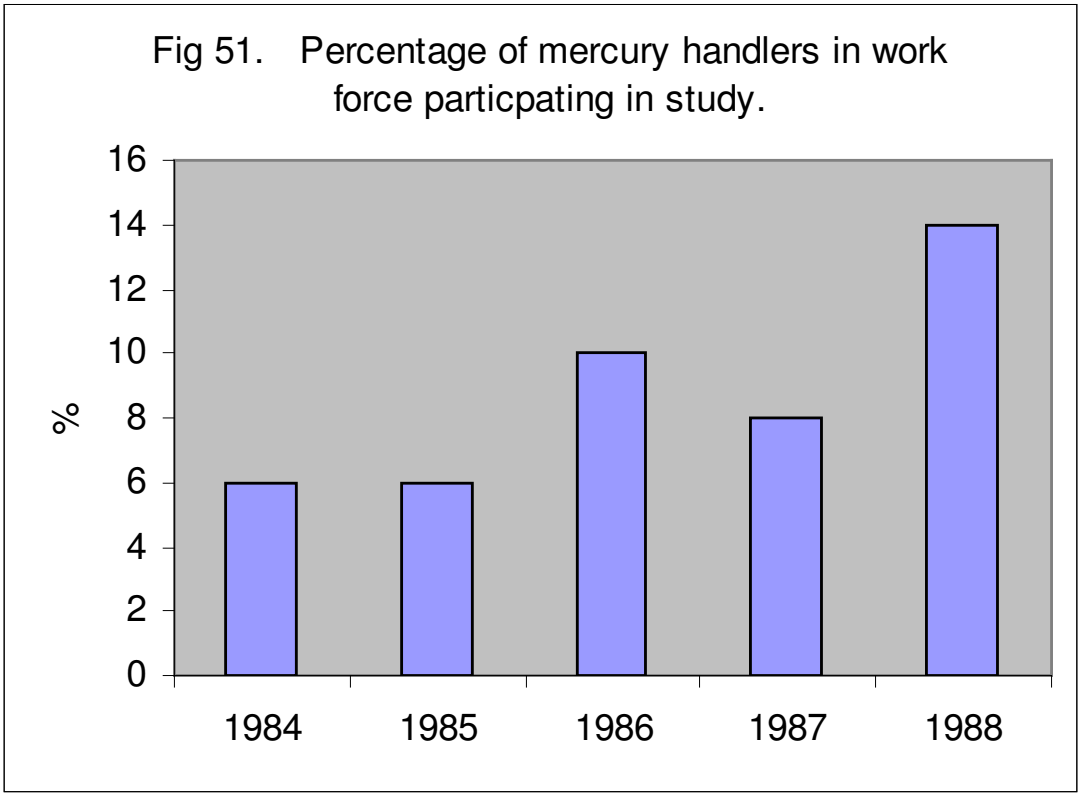


1984 n = 20; 1985 n = 21; 1986 n = 48; 1987 n = 48; 1988 n = 18.

Fig 51.

Graph of total number of mercury handlers [retort & non-retort] participating in the study as a percentage of the total gold mining workforce/year.

n = yearly total workforce.



1984 n = 200; 1985 n = 250; 1986 n = 300; 1987 n = 350; 1988 n = 200.

11.8.4 Control.

Control mercury urine [Hg-U] levels are shown in Fig 52 p 155 and are similar to what would be expected in the non-exposed general population <10 µgm/L [0.05 µmol/L] (WHO 1991). These represent 1 sample per year for 2.5 years, a total of 3 samples per control, and were used as comparison with the non–retorting and retorting group results, Fig 31 p133 & Fig 40 p143.

Fig 52.
The control group mean, minimum and maximum urinary mercury levels in µmol/L in the period 1986-1988.

n = total number of samples per year.

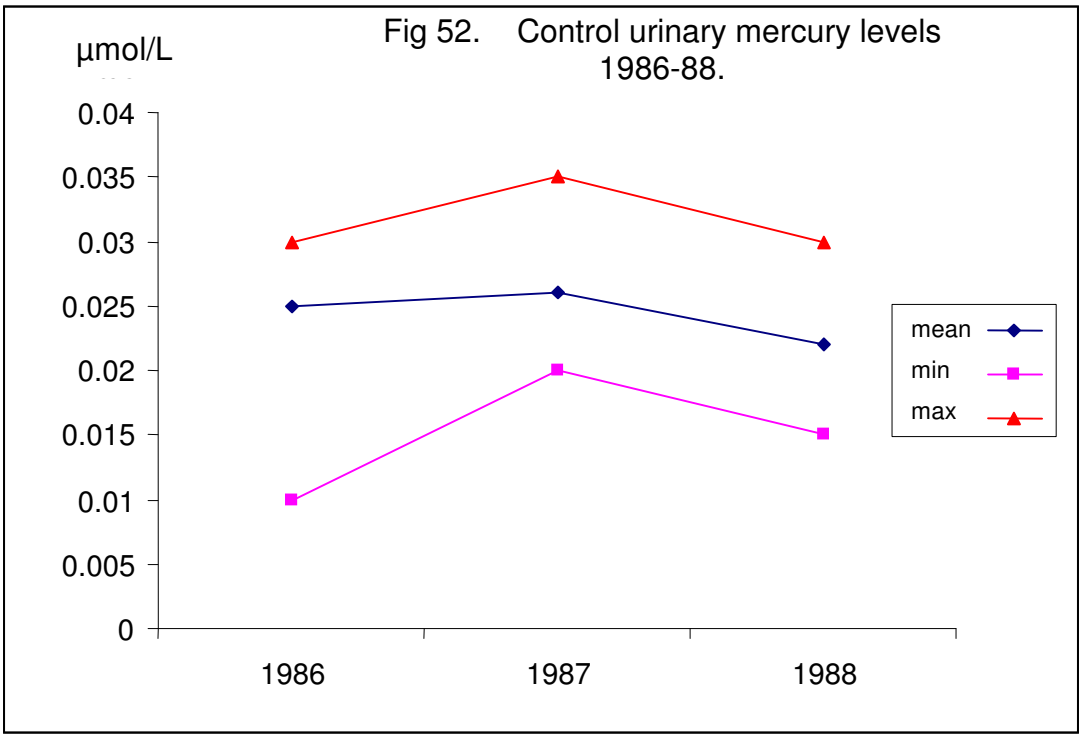


Fig 52. Control urinary mercury levels 1986-88.

1986 n=12; 1987 n=12; 1988 n=12.

11.8.5. Questionnaire.

Questionnaire responses are tabulated in tables 9–12 pp 157-158 and relate to the BEI Action level >0.25 µmol/L; Suspension level >0.5 µmol/L; and Controls. The normal or below Action levels [0.25 µmol/L] have not been tabulated. There are also no questionnaires for the historical samples 1984-85. All questionnaire responses for Action [n=22] and Suspension [n=16] criteria are included in tables 9 & 10 on p 157.

When a sample was collected the participant was asked to fill out a questionnaire and the tables indicate the subjective feelings of the participants at the time. There were a total of 16 mercury worker participants [8 retort and 8 non-retort workers] and they supplied 114 urine samples between January

1986 and June 1988. Over the study period [2.5 years] a total of 95 questionnaires [83%] were returned. The Control group [n=12] gave 36 urine samples in the 2.5 year period and returned 24 [67%] questionnaires as per table 11 p 158.

Only the questionnaire responses of the participants who recorded Action or Suspension level Hg-U results are included in the questionnaire tables 9 & 10 p157. In total 22 Action level [table 9] and 16 Suspension level responses [table 10] are recorded.

Tables 9-11 pp 157-158 record the listed symptoms that participants felt that they experienced at the time of urine collection. Table 12 p 158 shows a % increase in the numbers of mercury handlers experiencing symptoms as a comparison with the Controls. As their Hg–U levels rose their symptoms increased, namely: insomnia, fatigue, poor appetite and irritability. Some of these symptoms can be caused by sources other than mercury but, although not conclusive, the trend upward in some symptoms coinciding with increasing urinary mercury level is of interest and concern, and requires further attention. Tables 9 & 10 relate to the number of positive samples for Action or Suspension levels.

Table 9 records the number of questionnaires [n=22] returned indicating subjective responses for those workers above the Action level [>0.25 µmol/L] in period 1986-88.

Table 9.	Number of subjective responses for Action level participants.		[n = 22]
Symptoms	no	occasionally	often

Headache	14	8	0
Insomnia	15	6	1
Fatigue	16	6	0
Stomach problems	19	3	0
Poor appetite	15	7	0
Gum problems	22	0	0
Tremor	21	1	0
Irritability	14	7	1

Table 10 records the number of questionnaires [n = 16] returned indicating subjective responses for those workers above the Suspension level [>0.5 µmol/L] in period 1986-88.

Table 10. Number of subjective responses for Suspension level participants			[n = 16]
Symptoms	no	occasionally	often
Headache	6	8	2
Insomnia	10	6	0
Fatigue	7	6	3
Stomach problems	11	4	1
Poor appetite	8	6	2
Gum problems	13	2	1
Tremor	14	2	0
Irritability	6	8	2

Table 11 records the number of questionnaires [n] returned indicating subjective responses for Control participants in period 1986-88.

Table 11. Number of subjective responses for Controls.			[n=24]
Symptoms	no	occasionally	often

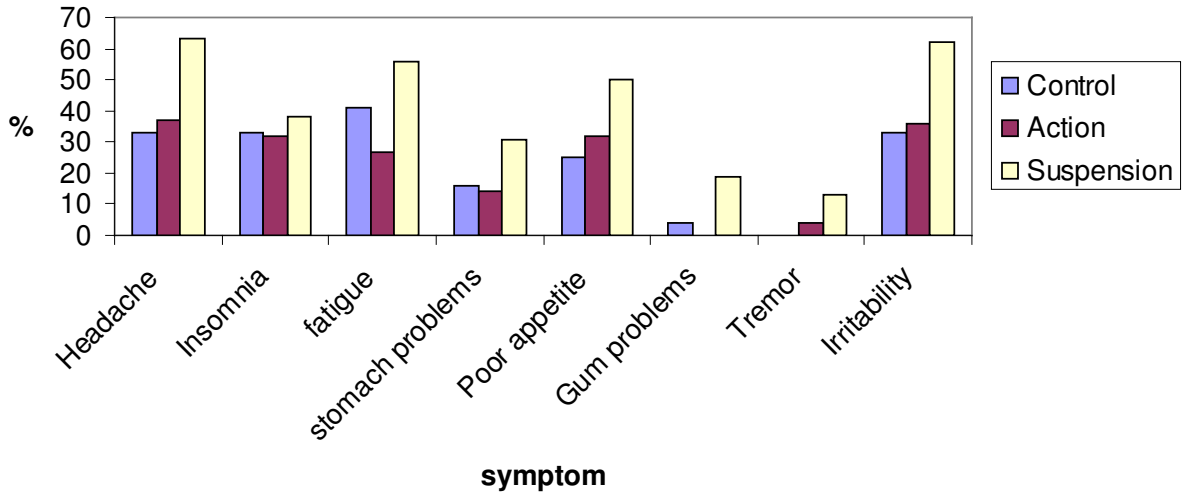
Headache	16	6	2
Insomnia	16	6	2
Fatigue	14	8	2
Stomach problems	20	3	1
Poor appetite	18	5	1
Gum problems	23	1	0
Tremor	24	0	0
Irritability	16	6	2

Table 12 records the % of workers [Action & Suspension level] and controls indicating subjective responses in the questionnaire.

Table 12.	% of subjective response.		
Symptoms	Control n = 24 %	Action level n = 22 %	Suspension level n = 16 %
Headache	33	37	63
Insomnia	33	32	38
Fatigue	41	27	56
Stomach problems	16	14	31
Poor appetite	25	32	50
Gum problems	4	0	19
Tremor	0	4	13
Irritability	33	36	62

Fig 53 graphs the percentage comparison between the responses of the Control, Action and Suspension level participants in this study. This graph relates to table 12.

Fig 53. Control and worker subjective response to questionaire 1986-88.



Control n = 24; Action level n = 22; Suspension level n = 16.

The percentage of questionnaire responses indicating some subjective feelings is too large to be ignored, especially when they are related to high mercury body burden as indicated by responder's mercury urine results. In particular, the increases in subjective feelings among the participants with results above the Suspension level should be taken seriously. This is a trend that needs to be researched further and in depth.

Chapter 12. Discussion.

12.1. General.

This study identified sources of mercury contamination and problem areas in the New Zealand gold mining industry that are a cause for concern. The World price of gold is a catalyst for gold mining becoming a viable industry within New Zealand once more. The concerns identified in this study need to be addressed to ensure that workers are protected from mercury toxicity. Mercury is still available and considered easy and cheap to use so it will remain the main means of recovering gold. This view is reinforced by current research papers (EPA 1997; Agency 1999; Hentschel et al. 2002).

We know mercury is not essential to living cells and performs no known biological function (NAS 1978) and most human exposure to biologically significant amounts of elemental mercury occurs in the workplace (Stopford et al. 1978; Roels et al. 1991). In the gold mining industry mercury is considered just another means to an end, a tool to achieve a desired result, with little thought given to the hazards associated with its use. In fact very little is known about its hazards by those required to use it.

In the gold mining industry mercury is released into the environment and work place through spillage, poor ventilation, bad work practice and poor house keeping. Mercury vapour released into the atmosphere upon heating may

condense when cooled and form small droplets on surfaces. Workers are exposed to mercury vapour levels in work rooms at levels above the TLV [0.05 mg/m^3]. Every work place visited during this study had a spillage problem. Most surfaces are not wetted by mercury so that drops tend to roll, enter small holes and cracks and mix easily with dust, or penetrate such substances as wood or brickwork. Pouring mercury without splashing or spilling is almost impossible, and any drops will break into smaller droplets too small to be seen but still available to vaporise. Because of the high surface tension of mercury, droplets are impossible to pick up making decontamination of an area where mercury has been spilt very difficult. At work sites visited spilt mercury was not cleaned up immediately and was spread around the site via footwear. In work places, mercury could be seen on work benches and floors where it was trapped in rough surfaces and cracks. Because of the large surface area of small droplets, the mercury easily re-vaporised and exceeded the TLV when the workplace temperature increased.

The retorting process added to the mercury vapour level in work rooms due to poor seals in the retorts that allowed significant amounts of mercury vapour to escape. Many retorts leaked and where there was no local ventilation system to exhaust this vapour outside it added to the existing room level. When a retort was opened a small cloud of grey vapour was seen to escape into the air space of the room. Measurement of this vapour confirmed that it was mercury. Dropping retorts on the floor after use was observed to result in

small mercury droplets that had adhered to the inside of the condenser spilling onto the floor.

Spilt mercury is a major source of vapour that is added to by other sources, e.g. retorting, poor housekeeping and poor storage of mercury contaminated equipment. These sources, combined with poor ventilation systems and poorly constructed work rooms, resulted in a contaminated work environment and a risk to worker's health. This risk was transferred, via footwear, to other work places where occupiers were unaware of the contamination. On observation of the transfer of mercury from room to room by footwear, arrangements were made to include air measurements of other than work rooms at some sites [table 8 p 129]. Air measurements were carried out as mentioned in the result section [see 11.7. p 128]. Rooms that were thought to be free of mercury were found to have significant levels of mercury vapour on hot days when the room temperature rose. Hg–air levels in these rooms ranged between 0.03-0.15 mg.Hg/m^3air with a mean 0.085 mg.Hg/m^3air. This is a significant finding because unmonitored workers were exposed to mercury contamination without their knowledge and, as this had not previously been recognised, no steps were being taken to prevent exposure or protect occupants in these rooms.

Although outside this study's objectives and not followed up, it is worth mentioning the transfer of mercury off-site. Many workplaces did not provide clothes washing facilities and the workers took their clothes home to be

washed. The contamination of footwear and clothing could create another health problem unrelated to the workplace; the potential for transfer of mercury from the workplace to the home thereby creating a risk to other family members. There is also the non-mercury handlers who have been shown to be at risk through inter-workplace transfer of mercury taking it home on their footwear and not being aware of this. As an example of the ease with which toxic materials can be unwittingly transferred to a home, the author was involved in an investigation of a lead poisoning case in a child some years ago. The child had no known contact with lead but investigation found high lead levels within the house and these were eventually traced to the father's clothing and boots which he wore at work and brought home. The mother would shake the overalls in the house to remove any loose dirt before washing them and the footwear was often worn into the house before being removed.

An article in USA Today (10/11/2000), gives an indication of the ease with which the transfer of toxic materials into homes can happen. The articles author Stephanie Armour, stated that an investigation found that employees in 35 States had unwittingly transported toxins away from work sites to their homes; and that families remain at risk in part because the health hazard has been widely ignored (personal papers). Mercury was mentioned as one of

those toxic materials. When transported off-site toxins are invisible or too small to be noticed, so family members may never know they've been put at

risk. They may be exposed if they touch a contaminated worker, handle his or her clothing or clean a house that contains hazards tracked in from the job.

Family members who clean the home can raise their risks or spread the hazard. When work clothes are washed the laundry area can become contaminated. Decontamination may be inadequate because small amounts of mercury can adhere to car seats, rugs, couches and other surfaces. Vacuuming up mercury can disperse the substance in the air, making it more readily absorbed.

Workplace substances that affect male workers may also indirectly cause harm to their families. Mercury unintentionally brought home by a worker may affect a woman's reproductive system or the health of an unborn child. Exposure to relatively high Hg° vapour concentrations has been reported to cause reproductive dysfunction in women and in laboratory animals (Schuurs 1999). It is not well known, however, that a man's exposure to substances in the workplace can affect his ability to have healthy children by altering hormones and sexual performance (NIOSH 1997). This needs to be investigated further and brought to worker's and management's attention.

The significance of the building construction and poor housekeeping of work rooms had a direct effect on the vaporisation of mercury. If there was no spillage then the building structure would be of no concern from a mercury

perspective. Being constructed of galvanised iron with no internal lining the building acted like an oven in summer when outside temperatures could reach >30^0C [86^0F] raising the inside temperature. These temperatures vaporised spilt mercury and room levels quickly rose above the TLV. The unlined wood structure inside was porous and absorbed mercury. In winter the building structure had less effect on mercury levels due to the colder outside temperatures.

Poor ventilation, or lack of, coupled with ongoing spillage added mercury to the room faster than it was removed and it was continually recycled. High mercury levels in workplaces were not always indicative of actual mercury usage and workers were exposed to higher levels than they were aware of.

Good ventilation is essential to ensure that vapours are removed from the work environment and only mechanical ventilation can achieve this. The release of mercury vapour into the work environment must be controlled by engineering methods to the extent reasonably practicable. The most effective control method is to enclose operations where mercury vapour may be released and to provide local exhaust ventilation and filtration. In an environment where there is little air movement, even at low temperatures, a high level of mercury vapour can accumulate as found in this study. Increased overall ventilation will increase vaporisation rates so all point sources of mercury, e.g. retorts, need local exhaust ventilation. Given the potential for increased evaporation of mercury due to increased air movement, other sources of vapour, such as spillages, need to be controlled

and removed. Good house keeping is critical and most sites visited had poor housekeeping processes allowing spilt mercury to be added to that already available for vaporisation. Measurements and observation proved that ventilation systems within the industry did not achieve adequate air changes with too much reliance put on natural ventilation as a means of mercury vapour removal and dilution. The release of mercury vapour into the work environment must be controlled by engineering methods where practicable and this should involve enclosing operations where mercury vapour may be released. Forced extraction systems, where provided, were usually associated with the retorting process and were switched off when retorting finished. They were not used to achieve room air changes to remove all mercury.

Mercury vapour in air levels [Hg–air] were the combined product of all the mercury sources previously mentioned created mercury vapour sources that continually added to the pool of mercury available to vaporise. It is worth repeating that poor ventilation was a critical factor in work rooms exceeding the TLV. Volatile metallic mercury, in a saturated atmosphere, contains approximately 18 mgHg/m^3 air at 24^0C [75^0F]. The exposure standard [0.05 mg/m^3] can easily be exceeded when metallic mercury is freely exposed to air, creating a risk of mercury poisoning by inhalation (Marsden 1992).

Mercury in air results in tables 4–6 on pp 123-126 confirm that, industry wide, the control of mercury vapour was ineffective and that this industry has a problem that needs attention. Evaluation of mercury in grab sample

measurements in tables 4 & 5 pp 123-125 give individual and group means that exceeded the TLV and are supported by the urinalysis levels. The study proved that work room vapour levels consistently exceeded the TLV and were a risk to worker's health. This is further confirmed in table 6 p 126 that records the ongoing Hg–air sampling that was done at the time of urine collection. This data was collated as a range and a mean for the period rather than each individual measurement being recorded and indicates that the mean for the group exceeded the TLV. The purpose of obtaining air samples is to determine specific sources of mercury vapour within the plant and to ascertain the effectiveness of clean-up and equipment decontamination procedures. The study proves the in-effectiveness of safety procedures in use in this industry.

Air samples should not be used as a substitute for personal exposure sampling as the purpose of personal air monitoring is to determine an individual's exposure to airborne metallic mercury vapour. The lack of suitable equipment to monitor peaks, as distinct from total concentration, was a major problem in this study and was only partially overcome by the use of personal monitors and instant reading of meters. There is a school of thought that personal samplers actually give better results than static samplers. Roels et al (1987) compared results obtained with the use of static samplers with results

from personal samplers and found that, in most of the workplaces, personal samplers yielded higher exposure levels [TWA] than did static samplers. As no peaks were recorded in this study there is no way of knowing whether

the workers were exposed to the concentration measured in one exposure or over the period that they wore the monitor.

Because of the inability to record peaks, the use of static, or grab samples, may have caused an error resulting in some measurements not being a true indication of individual exposure. However, any error would be under reporting rather than over reporting and, based on measurements, work sites were found to be a risk to workers. In some cases the meter was used to compare air measurements with the personal badge results. In most cases the badge showed higher exposure than monitoring with the meter. In only one out of six cases where this was done did the meter come close to the badge result.

Whilst air sampling can be used as a guide to good housekeeping it is not an absolute measure of personal exposure. Air sampling does not take into account the small amounts of mercury that can be absorbed through the skin or continued exposure outside work hours through the wearing of contaminated clothing. Contaminated skin and clothing are additional sources of mercury vapour that can be inhaled and such contamination can cause mercury vapour concentrations in the microenvironment of a worker that are several times higher than the concentration of the workplace air. Therefore,

breathing zone/ personal air samples should be used to estimate worker exposure where-ever possible.

12.2. Mercury in air & mercury in urine relationship.

A literature search noted that some of the early researchers (Smith 1970; Evans 1975) were of the opinion that the determination of mercury concentration in urine could only be used to estimate the exposure of a group of workers using the results on the basis of the geometric mean of a group being above or below a set figure to indicate whether compliance is being met. Piotrowski et al. (1975) demonstrated that the urinary mercury excretion in an individual may be assessed precisely enough provided that urine sampling is always performed at the same time, the concentration is corrected for specific gravity and the subject has been exposed for a sufficiently long time. Roels et al. (1987) stated that they had conclusive evidence, that excellent relationships could be established, on an individual basis between the daily intensity of mercury vapour exposure and daily mercury in urine levels. In this study the participants had all worked in the industry for at least 6 months before selection and the collection and analysis of samples in this study complied with current literature of the period.

There are a number of variables that should be considered in the collection and interpretation of the sampling results as mercury excretion from the body fluctuates considerably independent from exposure. Urinary mercury

measurement is considered reliable, simple and able to provide rapid identification of elevated mercury levels in an individual (Roels et al. 1987; Naleway et al. 1991). Yoshida (1985) found that urinary mercury levels

correlated better with exposure than blood mercury concentrations following long-term, low-level occupational exposure to elemental mercury vapour. Despite some minor differing of opinion many studies now agree that urine as an indicator of mercury in air exposure gives reliable results and that those results can be used to show exposure to high mercury in air levels (Lindstedt et al. 1979; Roels et al.1987; Barregård L. 1993; Nordhagen et al. 1994).

There is also agreement that a good correlation exists between urinary mercury levels and mercury in air levels (Stopford et al. 1978; Roels et al. 1987; Ehrenbeg et al. 1991; Tsjui et al. 2003).

In Figs 32-39 pp 134-141 the non - retorting mercury handlers had much lower mercury urine levels [Hg–U] than the retort handlers. This was expected due to their restricted handling of the metal and less time in mercury contaminated environments. Their Hg–U levels were higher than the Control group but, below the BEI and they were lower than the retort operator's minimum level. On an industry basis Fig 31 p 133, urinalysis results show the non–retort group mean below the guideline levels [BEI] and close to the maximum of the Control group Fig 52 p 155.

Figs 41-48 pp 144-151, indicate that where retort workers were monitored on a regular basis their Hg–U levels were high. When compared with the

Controls they were well above the “norm”. The mean of the retort workers ranged above the Action or Suspension levels. Using these results on a group basis Fig 40 p 143 the group mean was above the accepted level. The Hg-U levels, in conjunction with the Hg–air results, confirm that, on an industry basis, the control methods in use were ineffective and that workers were exposed to un-necessary risk from mercury contamination.

The correlation between the Hg–air and Hg–U in this study, confirm the relationship mentioned earlier (Lindstedt et al. 1979; Roels et al. 1987; Barregård L. 1993; Nordhagen et al. 1994), that urine as an indicator of mercury in air exposure gives reliable levels and that those results can be used to identify exposure to high mercury in air levels.

The study found that these workers had ongoing exposures and thereby were subjected to possible cumulative body burden unless their exposures were reduced. Without ongoing monitoring of work places by management, and an in place site plan of protective actions to be taken, such an event is highly probable. Discussions with management at the time of the study found that unless they were forced to do so by legislation nothing much would change and employees would remain at risk.

12.3. Microenvironment.

During the study it was observed that some participant's urine results were higher than could be explained by Hg–air measurements given the relationship between Hg–U and Hg-air. Long exposure periods were not the only cause of high biological levels of mercury in worker's as short exposure to high levels occurred frequently in this industry. In some cases the biological levels of workers rose rapidly between samples yet, on observation and measurement, they did not appear to be exposed to high Hg–air levels or, be exposed to contaminated environments for long periods.

Observation of process and practice led to concern that the measurement of mercury vapour within the work place might not be a true reflection of the worker's exposure level. To identify why/how this was occurring, it was decided to look closer at the personal environment of the individual worker i.e. his breathing zone. One area of interest was the possible contamination of clothing, especially overalls, which were known to be worn for long periods without washing or changing. This contamination of the clothing occurred during handling of the mercury and from being in the vapour contaminated rooms where the clothing absorbed mercury vapour. After work the overalls were often left in the work room where they continued to absorb vapours. Contamination of the skin and clothing can produce a source of mercury vapour than can be inhaled as it will be continuously released into the worker's breathing zone.

Another source of high environmental loading that could be associated with a microenvironment is the opening of the retort crucibles after retorting is

finished. The crucible was always removed from the retort to the floor to open and as mentioned in the result section a grey vapour, confirmed as mercury vapour, was observed to be released from the retort on opening. Because the retort operator stood bent over the retort to remove the crucible lid he was directly in line with the vapour coming off. This vapour was available as a high dose to breathe in at the time of retort opening and also contaminate clothing from where it was available to slowly release into the breathing zone of the wearer for the period that the clothing was worn. Breathing a high volume of mercury in a short time can poison the inhaler quickly. Contamination of clothing did not show up as part of the general room measurement and was not recorded as part of the worker's daily dose. The fact that a worker could go on breathing the vapours given off from his clothes after he had finished working with mercury, or being in a mercury contaminated room, was not acknowledged**.** If Hg–air levels are monitored, without reference to worker's microenvironments, it gives a false picture of their total dose. For this reason it is repeated that, breathing zone air samples should be used to estimate worker's true exposure to their total mercury burden.

This study confirmed that not only was a microenvironment created by the contamination of worker's clothing and that this contaminated a worker's breathing zone, but, that it continued to do so after they left contaminated rooms. Failure to consider the existence and importance of this microenvironment meant that a work room environmental measurement may

have complied with the TLV for mercury vapour, but the detrimental effect on the worker was not recognised nor was his true body burden measured. The existence of a microenvironment explains the discrepancy between the earlier high Hg–U levels and the Hg–air measurements in this study. Stopford et al. (1978) postulated on the basis of their research, that it was possible that the individual variability in mercury excretion is a true reflection of the variability of the external microenvironment of the worker that is not reflected by measuring the airborne concentration of mercury in the general work area. Roels et al. (1987) mentioned microenvironments and their contribution to overall exposures and the fact that microenvironment existence had been overlooked in earlier studies, particularly Smith et al. 1970. The existence of a microenvironment contamination is proven in this study and is evidence to account for some of the high urine levels in workers who were recorded as being exposed to low Hg–air levels. This is especially so where no other sources can be found.

Microenvironment have not been mentioned in recent studies, but it is noted that MOSHAB (2006) [Mines Occupational Safety & Health Board] in Western Australia have reinforced the need to consider microenvironments by stating in their Mining Guide, “that contaminated skin and clothing can produce additional sources of mercury vapour that can be inhaled and that such contamination can result in mercury vapour concentrations in a person’s microenvironment several times higher than the concentration in air of the general work environment.

Air sampling does not take into account the small amount of mercury that can be absorbed through the skin or continued exposure outside work hours through wearing contaminated clothing" (MOSHAB 2006). Senn (1996) also refers to microenvironments in her mining guide.

Microenvironments are an area of worker exposure that should be investigated and considered especially where high Hg–U levels can not be explained by measured Hg–air levels. They should be considered as part of any measurement program that looks at personal contamination or body burden. The carrying home of contaminated clothing and the potential to contaminate the home should also be given more attention.

12.4. Questionnaire.

The questionnaire used in this study was designed by the author and listed symptoms that are common to mercury poisoning. It was not peer reviewed and was used as an indicator of the subjective feelings of the worker's health at the time of urine collection and workers were not subjected to any medical, physiological or neurological examination. Roels et al. (1985) used a self administered questionnaire to detect symptoms of nervous system disturbances in their study of Belgian factory workers exposed to metallic mercury.

Although it is difficult to prove the presence of these symptoms were related to mercury contamination, or toxicity, without objective clinical testing, they

should not be ignored. Smith et al. (1970) found a significant relationship between mercury and the prevalence of various signs and symptoms [loss of appetite, tremor and insomnia] with 39% of his workers having an Hg–U of 0.5 µmol/L [100 µg/L] or greater. This study found 75% of workers with Hg-U levels 0.5 µmol/L or greater with similar symptoms. Roels et al. (1987) also found correlation between urine mercury levels and reported subjective symptoms of insomnia, tremor and loss of appetite.

Previous research has shown that in cases where low biological levels were found in mercury exposed workers, and no subjective response was indicated, the same workers, when asked to perform sensitive and objective tests showed signs of function impairment (Evans et al. 1975; Rosenman et al.1986). Studies with chronically exposed populations to high concentrations of mercury have shown cognitive, personality, sensory and motor function effects (Roels et al. 1982; Ehrenberg et al. 1991) and, whilst most people seem to recover if taken away from the source, not all do. There are studies that show that some effects [tremors and cognitive deficits] can still be observed 10 – 30 years after exposure (Albers et al. 1998; Mathiesen et al. 1999; Letz et al. 2000). Even where exposed workers do recover it can take a long period (McFarlane & Reigel 1978; Lilis et al.1985). Neurological testing of gold mine workers exposed to mercury is a subject for further research.

There is cause for concern that these subjective symptoms were being ignored, especially where consistently high Hg–U were involved, and there was a reluctance by management to consider that symptoms may have been

caused by mercury contamination. It is known that due to physiological variations, unusual sensitivity, or even some previous disease problems in individual cases, people can display symptoms at different biological levels and that these levels will range above and below the BEI. Some of these symptoms can be caused by other than mercury and, though it is not conclusive, the consistent indication by workers of these symptoms [insomnia, fatigue, poor appetite and irritability] coinciding with a rise in their urinalysis results is a worrying trend. Such trends should be followed up to ensure the workers are not being exposed to a life long problem. These symptoms are mentioned in other studies (Roels et al. 1987). In an assessment of studies on the exposure - response relationship between inhaled mercury vapour and adverse health effects, IPCS (2002) concluded that several studies consistently demonstrate subtle effects on the central nervous system in long-term occupational exposures to mercury vapour at exposure levels of approximately 20 $\mu g/m^3$ [0.02 mg/m^3] this figure is below the TLV (WHO/IPCS 2002). As this study measured consistently high mercury vapour levels in work rooms to which workers were exposed, and high urinalysis levels, the questionnaire responses have validity and need to be given serious consideration.

The lack of clinical testing of workers with high urinalysis results is an oversight that needs addressing and it should be mandatory for anyone with

an urinalysis result >0.5 µmol/L to have a clinical test. If such testing is not carried out the worker could have problems later in life. This is especially relevant given that tremor has been reported with long-term exposure to relatively low concentrations of mercury vapour (Chapman et al. 1990) and mild tremor may constitute an early adverse effect (Netterstrøm et al. 1996; Biernat et al. 1999).

Clinical testing is important when workers with consistently high biological levels are known to be working in an environment with high vapour levels, but, show no obvious symptoms. Without clinical testing at a set Action level, a progression to irreversible side effect is a possibility given current research.

12.5. Environmental pollution.

Although environmental pollution from mercury was not part of this study it is of interest and concern to note that environmental pollution did occur. It is known that mercury, along with cyanide, another gold saving chemical, was discharged to our waterways by the old miners (WCRC 2007). During this study the author was approached by a local ranger for the Acclimatisation Society [responsible for looking after game fish stocks in New Zealand rivers and streams] regarding the finding of high levels of mercury in some trout caught in the local Grey river. A major waterway on the West Coast, the Grey River is fed by other smaller rivers that were associated with gold mining in the past and currently.

There were 5 trout involved and the largest 1.05kg in weight had a level of 0.73 mg/kg. This was above the WHO maximum recommended limit of 0.5 mg/kg (WHO 1991). The other 4 trout were between 0.45 and 0.5 kg in weight and had levels between 0.05 and 0.14 mg/kg. All had been caught in the Grey River by local anglers.

Gold mining is a known source of mercury discharge to the environment as well as being a source of harm to the health of the handlers (WHO 1990; ATSDR 1999; UNEP 2005). Mercury which is not inhaled or collected during the gold saving process settles into the surrounding environment where it is absorbed and processed by a variety of living organisms. As mentioned in the toxicology review of mercury earlier in this study [chapter 5], this process transforms elemental mercury into methyl mercury, one of the most toxic organic compounds and a powerful neurotoxin (UNEP 2005). Due to bioaccumulation any biological organism exposed to that environment will take up mercury (Heiserman 1992). Since approximately 95% of all mercury used in small-scale gold mining around the world is released into the environment EPA (1997), this is an environmental as well as a human danger.

A very important factor in the impact of mercury on the environment is its ability to build up in the organisms and the food chain Lacerda (1997).

Inorganic mercury can also be absorbed, but is generally taken up at a slower rate and with lower efficiency than is methylmercury (EPA 1997). Because elemental mercury can be converted to methylmercury in aquatic

environments (Lindberg et al. 2001; Ullrich et al. 2001) this is what has happened in this local situation to contaminate the trout.

The Acclimatisation Society and the West Coast Regional Council decided to carry out some further research into the contamination of fish stock by mercury. Long finned eels, [Anguilla dieffenbachia] were considered the top predator in the local waterways and 11 eels were taken from 4 major waterways that had, at some time, gold mining in their catchments. The results showed levels of mercury from 0.1 to 0.5 mg/kg. The author of the report concluded that whilst there was some mercury pollution in the fish stock, the levels were not high enough to constitute a risk to humans consuming the fish unless they ate a large quantity. He did, however, add that it would only take a slight increase in biologically active mercury to put some fish into the critical zone. (Ryan 1989). This opinion is similar to one in a DSIR report that looked at mercury in trout in North Island waterways (Brooks et al. 1976).

The quantity of spilt mercury seen at gold mining sites during this survey, indicates that it is highly probable that most of this spillage is being washed into waterways directly and indirectly. A common way of trying to clean up a site was to hose it down and wash everything into the ground. The drains had no sumps or traps to capture wash down sediments before discharge to the environment. On some mining sites mercury was used outside and any spilt mercury was lost to the ground. At the time of the study the rules covering

discharges to the environment were weak and no one authority was responsible for oversight. This resulted in no monitoring of discharges.

Chapter 13. Conclusions.

13.1. General.

The use of mercury in the New Zealand gold mining industry creates a risk to the health of workers required to handle the metal. This study found that the risk increased through lack of knowledge regarding mercury's toxic properties and the work practices of the companies involved. High levels of mercury vapour were found in work rooms and on the clothing of workers, and a lack of basic safety procedures and equipment was noted. Microenvironments that were not acknowledged exist and add to worker's body burden of mercury.

Mercury contamination was measured in areas away from mercury workrooms e.g. staff rooms, lunch rooms and offices through transfer of spilt mercury via footwear and clothing. It is highly probable that mercury was transferred to worker's homes via footwear and contaminated clothing worn, or taken home to be washed.

Prevention of hazardous environments is essential to protect worker's health. The control of mercury would be more effective if a program for work place health and safety was available at all mining sites. As part of such a program an exposure control plan that will ensure staff are protected from over-exposure is required. The plan should set out procedures for on going monitoring of staff and environment.

13.2. Specific.

1. The gold mining industry creates a risk to the health of employees through contamination of work environments with metallic mercury. This is either directly from handling or working with the metal, including being in the mercury workroom or, indirectly through contamination of their work place by carry over of spilt mercury on footwear.

2. Spilt mercury was not cleaned up immediately making it available to be transported around work rooms, work site and off-site where it vaporised when room temperatures rose. Room mercury vapour levels were well above the New Zealand Threshold Limit value [TLV] making rooms a source of mercury exposure to anyone who entered.

3. Employees who did not work with mercury were put at unknown risk through the transfer of spilt mercury via footwear throughout the work site. Workers were not aware of this risk and not being monitored.

4. There is a high probability that mercury was transferred to worker's homes via footwear and clothing and family members were put at risk unknowingly. This was not followed up as it was not part of this study.

5. Mercury vapour levels in work rooms increased according to the type of building construction, with tin clad rooms absorbing the sun's heat and acting like ovens on hot days. This exposed workers to mercury vapour when no handling of mercury was taking place. As they were not aware of the situation the workers would take no precautions to protect themselves.

6. The industry as a whole failed to acknowledge the significance of poor work & hygiene practices in handling mercury. There was a large information gap in the knowledge of all people in this industry regarding the toxicity and properties of mercury and correct handling procedures. Workers who have contact with mercury must be made aware of toxic properties, the associated risk with handling it and protective procedures.

7. Subjective symptoms were ignored and not taken seriously, or as valid reasons to look at work practices and implement protective measures. The use of questionnaires to evaluate individual and group exposure is an essential tool in worker health monitoring in this industry.

8. Microenvironments are an important, but unacknowledged, source of contamination of a worker's breathing zone and increased body burden. Contaminated clothing was the main source of this microenvironment and such zones are a continuing source of worker contamination for as long as the clothes are worn.

Despite being a major source of contamination, microenvironments are easy to control by simply changing clothing daily and ensuring that they are washed at work and clean overalls supplied each day. Worker education regarding this is also an essential part.

9. There is a relationship between mercury urine levels and mercury air measurements that justifies using mercury urine results as a means of monitoring worker's mercury exposure. This ensures that a worker's total body burden is being measured and considered.

10. The use of the New Zealand BEI [Biological Exposure Indices] as a means to monitor and control mercury exposure in individual cases is acceptable so long as it is carried out according to recognised parameters. In conjunction with the other methods e.g. personal dose measurements and air measurements they will give useful data.

11. Well designed, forced air ventilation systems are essential in mercury work rooms and must provide minimum air changes. These should be supplied in conjunction with a filtered extraction system over the retort. Engineering technology should be used where needed as the use of respirators should be a last resort where there are no engineered solutions.

12. Scrupulous work practices and work room hygiene is essential to avoid the spillage of mercury and its transfer around work sites.

13. Despite the use of currently valid and acceptable methods of mercury measurement this study has shown that we may not always obtain a true/valid indication of a worker's exposure to mercury unless we have a monitoring plan that includes both personal and environmental air monitoring, measuring a worker's body burden and periodic medical monitoring in conjunction with testing worker's neurological symptoms.

14. The use and spillage of mercury, poor housekeeping, poor hygiene, carelessness and disposal of mercury waste, is a cause of mercury contamination of our waterways and the environment.

Chapter 14. Recommendations.

14.1. General.

The new Health and Safety in Employment Act 1992 [HSE] and the HSNO[11] Act 1996 are better tools for controlling compliance than the old legislation which they have replaced, so long as they are well administered. From 1992 OSH procedure has developed from, a hands on approach whereby inspectors visited sites and gave instruction on what was needed to comply; to one whereby self policing by companies is involved with minimal oversight by inspectors. This has led to a situation whereby OSH involvement is more an investigation after an accident, or incident, rather than prevention. If gold mining is to start again then this type of approach will not lead to improvement in the conditions/ problems found in the 1984-88 survey.

The Health and Safety in Employment Act 1992 [HSE] provides the authority for action to prevent and control most of the problems found in the survey and could be effective. However, this effectiveness can only be assured if OSH carry out their responsibilities and do not allow self policing to take place. During the original survey the mine owners had a vested interest in ensuring that costs were kept down [gold mining can be capital intensive] and they took shortcuts because no one checked them. Given that the same culture is

possible today, onsite visits and hands on control by inspectors will be necessary. OSH is the only department that has authority under both Acts [HSE & HSNO] in all workplaces therefore they are well placed to enforce the legislation. Goldmines are now workplaces, whereas at the time of the survey they were excluded due to the Mining legislation of the day placing them under the supervision of the mines inspectorate.

Section 12 of the HSE Act requires that employers must provide information about chemicals, their health and safety hazards, how to use the chemicals correctly and safely, and how to respond in emergency situations. The employer must ensure that the information is presented in a form the employee can understand and in a way that it is always readily available. The employer must also provide training in the safe use of chemicals and the protective clothing and equipment that the employee is required to use.

Information is best provided as a Material Safety Data Sheet [MSDS] for the chemical concerned. A MSDS [which should be available from the chemical supplier or manufacturer – see appendix 3] has concise information on:

- Identification of name, formula, uses, physical description/properties, and ingredients:
- Health hazard information e.g. health effects, acute and chronic; first aid:

[11] The HSNO Act 1996 covers the importation and use of all hazardous substances and organisms within New Zealand. Regulations under the Act cover importation/ use and destruction.

- Precautions for use e.g. exposure standards, engineering controls, personal protection, flammability:
- Safe handling information e.g. storage and transport, spills and disposal, fire/explosion hazard.

The enforcement of this section of the Act by OSH would ensure that employers met their obligation to make their employees aware of the hazards involved with the use of mercury, a major omission identified in the survey.

The HSE Act also requires that where a worksite has significant hazards that could result in harm to an employee, the employer must provide suitable protective equipment and/ or suitable personal protective clothing. Section 7 of the HSE Act requires the employer to have in place effective methods to systematically identify and assess hazards. To carry out a thorough assessment of the hazards created by the storage, handling, use and disposal of hazardous substances to enable adequate control measures to be implemented. Employers need to determine the magnitude of the risks to employees and then ensure that all practicable steps are taken to minimise those risks. OSH enforcement of this section would bring the lack of protective equipment and inadequate facilities previously identified under control and reduce the likelihood of worker contamination and possible home transfer of mercury.

Another method of controlling harm to employees is the use of Managing Substances Hazardous to Health codes [MOSHH]. These codes require employers to consider two [2] types of monitoring:

1. Measuring employee's exposure to a hazardous substance; and

2. Checking employee's health in relation to the exposure. Both workplace exposure monitoring and health surveillance may be necessary to ensure that exposure to hazardous substances is being adequately controlled.

The use of MOSHH would go some way to ensuring that goldminers were being monitored on a regular basis and that action was taken on those results. Given adequate involvement by OSH and the drawing up of approved sampling programmes, personal contamination and microenvironments could be measured and controlled. Determined use of the HSE Act by OSH would mean that mine owners would have to clean up their operations and provide proper facilities and workrooms for the safe use of mercury. The HSE Act provides the power to control gold mining and prevent the problems identified in the 1984-88 survey so long as the authorities insist on using and enforcing the legislation.

The HSNO Act and Regulations provides adequate controls to ensure that mercury, as a controlled substance, has its use recorded from importation, through use, to disposal. This would prevent much of the waste to the atmosphere and ground and water pollution. Again this can only happen if the Authorities police the legislation as intended. This new legislation gives OSH many powers and they are the one organisation that can use both the HSNO and HSE Acts in the workplace.

The legislation available today means that if gold mining is started again mercury use should be better controlled, and worker's health should not be at

risk, as it was in the 1980s. However, self policing by the industry as a means of protecting worker safety should not be allowed. This has not worked in the past and will not work in the future. There is too much vested interest by mine owners. Worker safety will only be achieved if the OSH inspectorate is involved in visiting the mines on a regular basis, ensuring that monitoring takes place and legislation is enforced. The new legislation sets out many requirements and the penalties are high for failure to comply. Prosecution should be mandatory for any employer who willingly fails to protect their workers. The prevention of harm to workers must be paramount in this industry. It is the author's opinion that, despite HSE and HSNO requirements, without the regular presence of OSH inspectors on site, and enforcement of conditions, there will be minimal change in this industry.

Based on the findings of this study the following recommendations should be acted on to ensure that any use of mercury in the New Zealand gold mining industry does not put workers, and/or others, at risk.

14.2. Specific**.**

1. The control and remedying of problems found in this study can only be achieved by an enforceable code of practice, good education, policing, and strict application of the legislation by OSH.

2. The industry must be monitored more regularly by the Authorities as self policing has not worked in the past. This will require a change in mind set by the Authorities.

3. There are efficient, modern, mechanical methods of saving gold available that should be made known to the industry as a replacement for mercury. The use of these should be encouraged.

4. Subjective symptoms should be accepted as part of the monitoring of mercury exposure where urinary results are over the BEI action level.

5. A total sampling regime should be established by employers in collaboration with OSH that takes account of subjective feelings [from questionnaire or other means], mercury in urine, personal air monitoring, air measurement and microenvironments, and where necessary, neurological testing. As mentioned in 14.1.the existence of MOSHH in the legislation makes this possible.

6. Microenvironments must be acknowledged and accepted as a critical part of any monitoring program in 5 above. Not including them will make any measurement of a worker's exposure incomplete and will not give a complete indication of their total mercury exposure.

7. Clinical testing should be mandatory for any person with an urinalysis result >0.5 µmol/L [BEI].

8. Sumps to catch any sediment during wash down of mercury contaminated areas must be a compulsory part of any licence to use mercury. Disposal of waste from these sumps must be to approved facilities. HSNO legislation should be used to achieve this.

9. Mercury is a classified toxic substance under HSNO [class 6;8;9]. OSH policing of HSNO in terms of workplaces/ operations would ensure that the use of this chemical was controlled.

Chapter 15. Limitations and Bias.

15.1. Limitations.

This study was restricted by several limitations. These include:

- The shortage of personal dose badges. This was a supply and finance problem and was not able to be overcome. A larger supply of badges would have enabled more sampling of personal air zones and given a better indication of the true level of personal contamination.

- The overloading of the mercury meter. Because of the high levels of mercury vapour found in work rooms during this study the meter often became overloaded. This was a technical limitation of the instrument as it worked on a gold foil absorption process and the gold foil became overloaded/ saturated if mercury vapours were too high [>1 mg/m^3]. When this occurred the instrument had to be cleansed by burning off the foil, an internal process in the instrument that was manually initiated. This took time, sometimes as long as 15 minutes, and made measurement difficult when used in saturated work places.

- The inability to log any measured peak loadings meant that there was no way of knowing whether an unattended reading was influenced by a sudden release of vapour , was the days accumulated measurement. At the time of the study there were limited instruments available to carry out any measurement of peak loadings. The equipment available was too expensive to hire given the length and funding availability of this study and they were in short supply. As this study had limited funds and was over a long time period, they were not utilised.

- Finance was short so the use of equipment to carry out measurements was restricted to what was available in the local office and what could be borrowed from other offices/ departments.

- The necessity of fitting visits in with gold mining company work schedules and some restricted access made for difficulties in carrying out some measurements to fit within the study timeframe.

- The lack of control; over some of the sampling data. e.g. The use of lapel badges meant that the wearer was not observed all day and there was no way of telling whether some of the higher reading were not deliberate contamination. Trust was a big part of this study.

15.2. Bias.

A method of categorising systematic research errors is by classifying them in to two general classes: Selection and Observation bias (Hennekens & Buring 1987).

1. Selection bias.

   Site choice: The work sites were chosen to be representative of size and type but a limitation was that they had to be reasonably accessible and within a reasonable travel distance. This meant that some of the more isolated and distant sites were not included. Some companies put restrictions on access that ruled them out of contention. There was also a cost factor in travel to sites that ruled distant sites out.

   Site visits: The mine sites could only be studied if the mine owners were willing to allow visits. Those that were not willing may have been sites where conditions were bad or they may have thought that my presence would interrupt work. The number of sites that were willing to allow visits was considered representative enough to ensure validity to the finding.

   Participant choice: The selection of participants was largely controlled by the willingness of both companies and workers to be involved.

2. Observation bias.

   Observing:

   Observation of work practice was a necessary part of this study but, it is possible that although the employees being observed were willing participants, they may have changed consciously or un-consciously their routine to fit in with what they perceived the study to be looking for.

   Interviewing:

   Interviewing employees could bias an observer in favour of the employees and affect the attitude to the company. Some of the interview questions, especially in regard to personal health and work conditions, were sensitive to the participants. The question of honesty in answers given is a critical factor and not one that is easy to determine.

Some of the bias was difficult to overcome during the study, mainly due to lack of recognition at the start and a limitation on time and finance. Most of them could be overcome in future research where confounding issues could be accounted for.

Chapter 16. Areas for Additional Research.

16.1. Gaps.

Identified gaps in knowledge:

1. The existence of microenvironments. This is an area of research that needs to be developed further. Failure to acknowledge the existence of microenvironments that affect a worker's breathing zone will mean that a worker's true exposure to mercury vapour is not measured. If reliance is given to just measuring room vapour levels then exposed workers will continue to be at risk and monitoring will not be valid or moral.

2. Worker's subjective symptoms can have a relationship to their mercury exposure. Subjective feelings should be acknowledged and followed up. More work needs to be done on this and the clinical testing of mercury handlers and those exposed to mercury.

3. The likelihood that workers could carry mercury off-site and thereby contaminate their home environment is an issue that this study observed as a distinct probability. It needs to be researched further to identify if this is happening and if it is, to what extent. Such contamination could be a risk to families without them being aware.

4. The identification of alternative methods of recovering gold from the sediments needs to be explored. Although there appears to be other methods mentioned during this study it was difficult to find any freely available information on them.

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Appendix 1.

Mercury questionnaire.

Would you please answer the following questions. The results will be used as part of our assessment. This information is confidential. Thank you.

Smoker yes / no Age: F / M

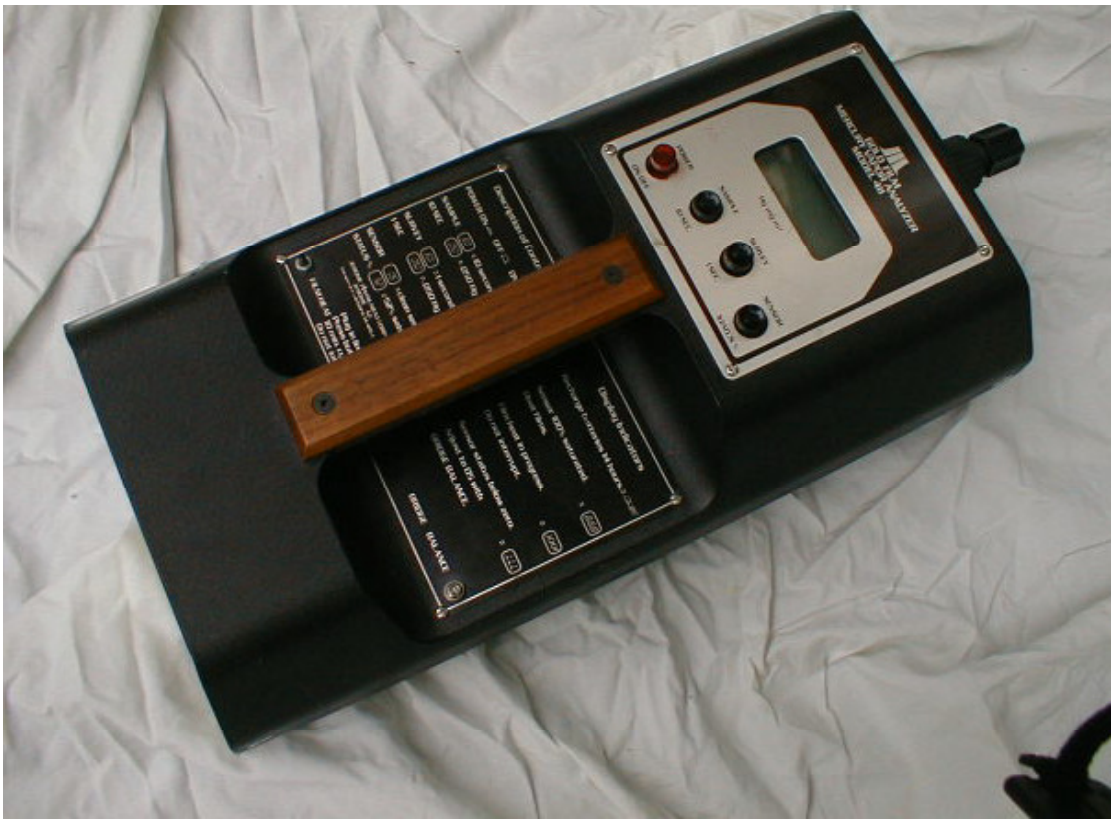
Do you suffer from any of the following symptoms?

1. Headache no / occasionally / often
2. Insomnia no / occasionally / often
3. Fatigue no / occasionally / often
4. Stomach problems no / occasionally / often
5. poor appetite no / occasionally / often
6. Gum problems no / occasionally / often
7. Tremors / shakes no / occasionally / often
8. Irritability no / occasionally / often

Are there any other health problems you have noticed since handling mercury?

Appendix 2.

Mercury Vapour Sniffer [analyser]



Appendix 3.

Material Safety Data Sheet

Mercury

Section 1: Chemical Product and Company Identification
Product Name: Mercury
Catalog Codes: SLM3505, SLM1363
CAS#: 7439-97-6
RTECS: OV4550000
TSCA: TSCA 8(b) inventory: **Mercury**
CI#: Not applicable.
Synonym: Quick Silver; Colloidal **Mercury**; Metallic **Mercury**; Liquid Silver; Hydragyrum
Chemical Name: Mercury
Chemical Formula: Hg
Contact Information:
Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396
US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**
Order Online: ScienceLab.com
CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300
International CHEMTREC, call: 1-703-527-3887
For non-emergency assistance, call: 1-281-441-4400
Section 2: Composition and Information on Ingredients
Composition:

Name	**CAS #**	**% by Weight**
Mercury	7439-97-6	100

Toxicological Data on Ingredients: Mercury LD50: Not available. LC50: Not available.
Section 3: Hazards Identification
Potential Acute Health Effects:
Very hazardous in case of skin contact (irritant), of eye contact (irritant), of ingestion, of inhalation. Hazardous in case of skin contact (corrosive, permeator). Liquid or spray mist may produce tissue damage particularly on mucous membranes of eyes, mouth and respiratory tract. Skin contact may produce burns. Inhalation of the spray mist may produce severe irritation of respiratory tract, characterized by coughing, choking, or shortness of breath. Severe over-exposure can result in death. Inflammation of the eye is characterized by redness, watering, and itching. Skin inflammation is characterized by itching, scaling, reddening, or, occasionally, blistering.

Potential Chronic Health Effects:
Hazardous in case of skin contact (permeator).
CARCINOGENIC EFFECTS: Classified A5 (Not suspected for human.) by ACGIH. 3 (Not classifiable for
human.) by IARC.
MUTAGENIC EFFECTS: Not available.
TERATOGENIC EFFECTS: Not available.

DEVELOPMENTAL TOXICITY: Not available.
The substance may be toxic to blood, kidneys, liver, brain, peripheral nervous system, central nervous system (CNS). Repeated or prolonged exposure to the substance can produce target organs damage. Repeated or prolonged contact with spray mist may produce chronic eye irritation and severe skin irritation. Repeated or prolonged exposure to spray mist may produce respiratory tract irritation leading to frequent attacks of bronchial infection. Repeated exposure to a highly toxic material may produce general deterioration of health by an accumulation in one or many human organs.

Section 4: First Aid Measures

Eye Contact:
Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Cold water may be used. WARM water MUST be used. Get medical attention immediately.

Skin Contact:
In case of contact, immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Cover the irritated skin with an emollient. Wash clothing before reuse. Thoroughly clean shoes before reuse. Get medical attention immediately.

Serious Skin Contact:
Wash with a disinfectant soap and cover the contaminated skin with an anti-bacterial cream. Seek immediate medical attention.

Inhalation:
If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical attention immediately.

Serious Inhalation:
Evacuate the victim to a safe area as soon as possible. Loosen tight clothing such as a collar, tie, belt or waistband. If breathing is difficult, administer oxygen. If the victim is not breathing, perform mouth-to-mouth resuscitation. WARNING: It may be hazardous to the person providing aid to give mouth-to-mouth resuscitation when the inhaled material is toxic, infectious or corrosive. Seek immediate medical attention.

Ingestion:
Do NOT induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. If large quantities of this material are swallowed, call a physician immediately. Loosen tight clothing such as a collar, tie, belt or waistband.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: Non-flammable.

Auto-Ignition Temperature: Not applicable.

Flash Points: Not applicable.
Flammable Limits: Not applicable.
Products of Combustion: Not available.
Fire Hazards in Presence of Various Substances: Not applicable.
Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.
Fire Fighting Media and Instructions: Not applicable.

Special Remarks on Fire Hazards:
When thrown into **mercury** vapor, boron phosphodiiodide ignites at once. Flame forms with chlorine jet over **mercury** surface at 200 deg to 300 deg C. **Mercury** undergoes hazardous reactions in the presence of heat and sparks or ignition.
Special Remarks on Explosion Hazards:
A violent exothermic reaction or possible explosion occurs when **mercury** comes in contact with lithium and rubidium.
CHLORINE DIOXIDE & LIQUID HG, WHEN MIXED, EXPLODE VIOLENTLY.
Mercury and Ammonia can produce an explosive compound.
A mixture of the dry carbonyl and oxygen will explode on vigorous shaking with **mercury**. Methyl azide in the presence of **mercury** was shown to be potentially explosive.
Section 6: Accidental Release Measures
Small Spill: Absorb with an inert material and put the spilled material in an appropriate waste disposal.
Large Spill:
Corrosive liquid. Poisonous liquid.
Stop leak if without risk. Absorb with DRY earth, sand or other non-combustible material. Do not get water inside container. Do not touch spilled material. Use water spray curtain to divert vapor drift. Use water spray to reduce vapors. Prevent entry into sewers, basements or confined areas; dike if needed. Call for assistance on disposal. Be careful that the product is not present at a concentration level above TLV. Check TLV on the **MSDS** and with local authorities.
Section 7: Handling and Storage
Precautions:
Keep locked up.. Keep container dry. Do not ingest. Do not breathe gas/fumes/ vapor/spray. Never add water to this product. In case of insufficient ventilation, wear suitable respiratory equipment. If ingested, seek medical advice immediately and show the container or the label. Avoid contact with skin and eyes. Keep away from incompatibles such as oxidizing agents, metals.
Storage: Keep container tightly closed. Keep container in a cool, well-ventilated area. Do not store above 25°C (77°F).

Section 8: Exposure Controls/Personal Protection

Engineering Controls:

Provide exhaust ventilation or other engineering controls to keep the airborne concentrations of vapors below their respective threshold limit value. Ensure that eyewash stations and safety showers are proximal to the work-station location.

Personal Protection:

Face shield. Full suit. Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Gloves. Boots.

Personal Protection in Case of a Large Spill:

Splash goggles. Full suit. Vapor respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:

TWA: 0.025 from ACGIH (TLV) [United States] SKIN
TWA: 0.05 CEIL: 0.1 (mg/m3) from OSHA (PEL) [United States] Inhalation
TWA: 0.025 (mg/m3) [United Kingdom (UK)]
Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Liquid. (Heavy liquid)
Odor: Odorless.
Taste: Not available.
Molecular Weight: 200.59 g/mole
Color: Silver-white
pH (1% soln/water): Not available.
Boiling Point: 356.73°C (674.1°F)
Melting Point: -38.87°C (-38°F)
Critical Temperature: 1462°C (2663.6°F)
Specific Gravity: 13.55 (Water = 1)
Vapor Pressure: Not available.
Vapor Density: 6.93 (Air = 1)
Volatility: Not available.
Odor Threshold: Not available.
Water/Oil Dist. Coeff.: Not available.
Ionicity (in Water): Not available.
Dispersion Properties: Not available.
Solubility: Very slightly soluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.
Instability Temperature: Not available.
Conditions of Instability: Incompatible materials
Incompatibility with various substances: Reactive with oxidizing agents, metals.
Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity:
Ground mixtures of sodium carbide and **mercury**, aluminum, lead, or iron can react vigorously. A violent exothermic reaction or possible explosion occurs when **mercury** comes in contact with lithium and rubidium.
Incompatible with boron diiodophosphide; ethylene oxide; metal oxides, metals(aluminum, potassium, lithium, sodium, rubidium); methyl azide; methylsilane, oxygen; oxidants(bromine, peroxyformic acid, chlorine dioxide, nitric acid, tetracarbonynickel, nitromethane, silver perchlorate, chlorates, sulfuric acid, nitrates,); tetracarbonylnickel, oxygen, acetylinic compounds, ammonia, ethylene oxide, methylsiliane, calcium,
Special Remarks on Corrosivity:
The high mobility and tendency to dispersion exhibited by **mercury**, and the ease with which it forms alloys (amalga) with many laboratory and electrical contact metals, can cause severe corrosion problems in laboratories.
Special precautions: **Mercury** can attack copper and copper alloy materials.
Polymerization: Will not occur.
Section 11: Toxicological Information
Routes of Entry: Absorbed through skin. Dermal contact. Eye contact. Inhalation. Ingestion.
Toxicity to Animals:
LD50: Not available.
LC50: Not available.
Chronic Effects on Humans:
CARCINOGENIC EFFECTS: Classified A5 (Not suspected for human.) by ACGIH. 3 (Not classifiable for
human.) by IARC.
May cause damage to the following organs: blood, kidneys, liver, brain, peripheral nervous system, central nervous system (CNS).
Other Toxic Effects on Humans:
Very hazardous in case of skin contact (irritant), of ingestion, of inhalation.
Hazardous in case of skin contact (corrosive, permeator).
Special Remarks on Toxicity to Animals: Not available.
Special Remarks on Chronic Effects on Humans:
May affect genetic material.
May cause cancer based on animal data.
Passes through the placental barrier in animal.
May cause adverse reproductive effects(paternal effects- spermatogenesis; effects on fertility - fetotoxicity, post-implantation mortality), and birth defects.
Special Remarks on other Toxic Effects on Humans:
Section 12: Ecological Information
Ecotoxicity: Not available.
BOD5 and COD: Not available.
Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.
Toxicity of the Products of Biodegradation: The products of degradation are less toxic than the product itself.
Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations
Waste Disposal:
Waste must be disposed of in accordance with federal, state and local environmental control regulations.
Section 14: Transport Information
DOT Classification: Class 8: Corrosive material

Identification: : **Mercury** UNNA: 2809 PG: III
Special Provisions for Transport: Not available.
Section 15: Other Regulatory Information
Federal and State Regulations:
California prop. 65: This product contains the following ingredients for which the State of California has found to cause cancer, birth defects or other reproductive harm, which would require a warning under the statute: **Mercury**
California prop. 65: This product contains the following ingredients for which the State of California has found to cause birth defects which would require a warning under the statute: **Mercury**
Connecticut hazardous material survey.: **Mercury**
Illinois toxic substances disclosure to employee act: **Mercury**
Illinois chemical safety act: **Mercury**
New York acutely hazardous substances: **Mercury**
Rhode Island RTK hazardous substances: **Mercury**
Pennsylvania RTK: **Mercury**
Minnesota: **Mercury**
Massachusetts RTK: **Mercury**
New Jersey: **Mercury**
New Jersey spill list: **Mercury**
Louisiana spill reporting: **Mercury**
California Director's List of Hazardous Substances.: **Mercury**
TSCA 8(b) inventory: **Mercury**
SARA 313 toxic chemical notification and release reporting: **Mercury**
CERCLA: Hazardous substances.: **Mercury**: 1 lbs. (0.4536 kg)
Other Regulations:
OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).
EINECS: This product is on the European Inventory of Existing Commercial Chemical Substances.
Other Classifications:
WHMIS (Canada):
CLASS D-1A: Material causing immediate and serious toxic effects (VERY TOXIC).
CLASS D-2A: Material causing other toxic effects (VERY TOXIC).
CLASS E: Corrosive liquid.
DSCL (EEC):
R23- Toxic by inhalation.
R33- Danger of cumulative effects.
R38- Irritating to skin.
R41- Risk of serious damage to eyes.
R50/53- Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.

S2- Keep out of the reach of children.
S7- Keep container tightly closed.
S26- In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S39- Wear eye/face protection.
S45- In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S46- If swallowed, seek medical advice immediately and show this container or label.
S60- This material and its container must be disposed of as hazardous waste.

S61- Avoid release to the environment. Refer to special instructions/Safety data sheets.
HMIS (U.S.A.):
Health Hazard: 3
Fire Hazard: 0
Reactivity: 0
Personal Protection:
National Fire Protection Association (U.S.A.):
Health: 3
Flammability: 0
Reactivity: 0
Specific hazard:
Protective Equipment:
Gloves.
Full suit.
Vapor respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate.
Face shield.
Section 16: Other Information
References: Not available.
Other Special Considerations: Not available.
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